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STRUCTURES AND DYNAMICS DIVISION RESEARCH AND TECHNOLOGY PLANS FOR FY 1987 AND ACCOMPLISHMENTS FOR FY 1986

Kay S. Bales

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National Aeronautics and Space Administration

Langley Research Center
Hampton, Virginia 23665

RESEARCH AND TECHNOLOGY PLANS FOR FY 1987

AND ACCOMPLISHMENTS FOR FY 1986

BY

KAY S. BALES

SUMMARY

The purpose of this report is to present the Structures and Dynamics Division's research plans for FY 1987 and accomplishments for FY 1986. The work under each branch is shown by RTR Objectives, FY 1987 Plans, Approach, Milestones, and FY 1986 Accomplishments. Logic charts show elements of research and rough relationship to each other. This information is useful in program coordination with other government organizations in areas f mutual interest.

ORGANIZATION

The Langley Research Center is organized by directorates as shown on figure 1. The Structures Directorate includes Structures and Dynamics Division, Materials Division, Loads and Aeroelasticity Division, and Acoustics Division. The Structures and Dynamics Division consists of four branches as shown on figure 2. There has been one significant change in the organizational structure of the Division. Mr. Brantley R. Hanks was selected Head, Structural Dynamics Branch. Dr. Larry D. Pinson also is currently Acting Head, Impact Dynamics Branch.

FUNCTIONAL STATEMENT

The Division conducts analytical and experimental research to achieve structures which meet functional requirements of advanced atmospheric and space flight vehicles. Provides experimental data and analytical methods for predicting stresses, deformations, structural strength, and dynamic response. Investigates interaction of structure with propulsion and control systems, landing dynamics, crash dynamics, and resulting structural response. Develops and evaluates structural configurations embodying new material systems and/or advanced design concepts for general application and for specific classes or new aerospace vehicles. Develops advanced structural analysis

methods and computer programs. Uses a broad spectrum of test facilities and develops new research techniques. Test facilities include the Structures and Materials Laboratory, Structural Dynamics Research Laboratory, Impact Dynamics Research Facility and the Aircraft Landing Dynamics Facility. Data are also obtained and analyzed from flight investigations.

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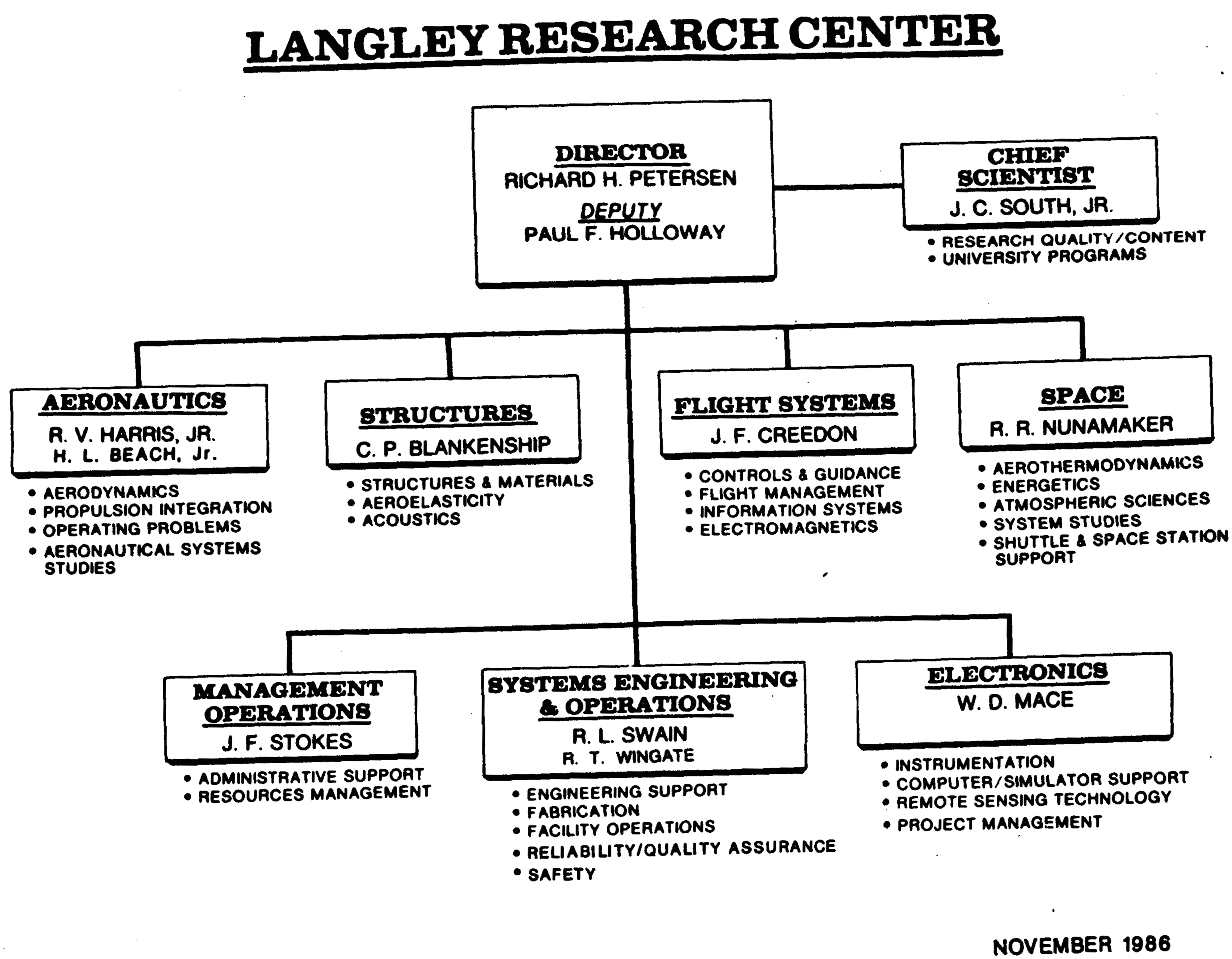
LANGLEY RESEARCH CENTER
DIRECTOR
RICHARD H. PETERSEN
DEPUTY
PAUL F. HOLLOWAY
CHIEF SCIENTIST
J. C. SOUTH, JR.
• RESEARCH QUALITY/CONTENT
• UNIVERSITY PROGRAMS
AERONAUTICS
R. V. HARRIS, JR.
H. L. BEACH, Jr.
• AERODYNAMICS
• PROPULSION INTEGRATION
• OPERATING PROBLEMS
• AERONAUTICAL SYSTEMS STUDIES
STRUCTURES
C. P. BLANKENSHIP
• STRUCTURES & MATERIALS
• AEROELASTICITY
• ACOUSTICS
FLIGHT SYSTEMS
J. F. CREEDON
• CONTROLS & GUIDANCE
• FLIGHT MANAGEMENT
• INFORMATION SYSTEMS
• ELECTROMAGNETICS
SPACE
R. R. NUNAMAKER
• AEROTHERMODYNAMICS
• ENERGETICS
• ATMOSPHERIC SCIENCES
• SYSTEM STUDIES
• SHUTTLE & SPACE STATION SUPPORT
MANAGEMENT OPERATIONS
J. F. STOKES
• ADMINISTRATIVE SUPPORT
• RESOURCES MANAGEMENT
SYSTEMS ENGINEERING & OPERATIONS
R. L. SWAIN
R. T. WINGATE
• ENGINEERING SUPPORT
• FABRICATION
• FACILITY OPERATIONS
• RELIABILITY/QUALITY ASSURANCE
• SAFETY
ELECTRONICS
W. D. MACE
• INSTRUMENTATION
• COMPUTER/SIMULATOR SUPPORT
• REMOTE SENSING TECHNOLOGY
• PROJECT MANAGEMENT
NOVEMBER 1986

Figure 1.

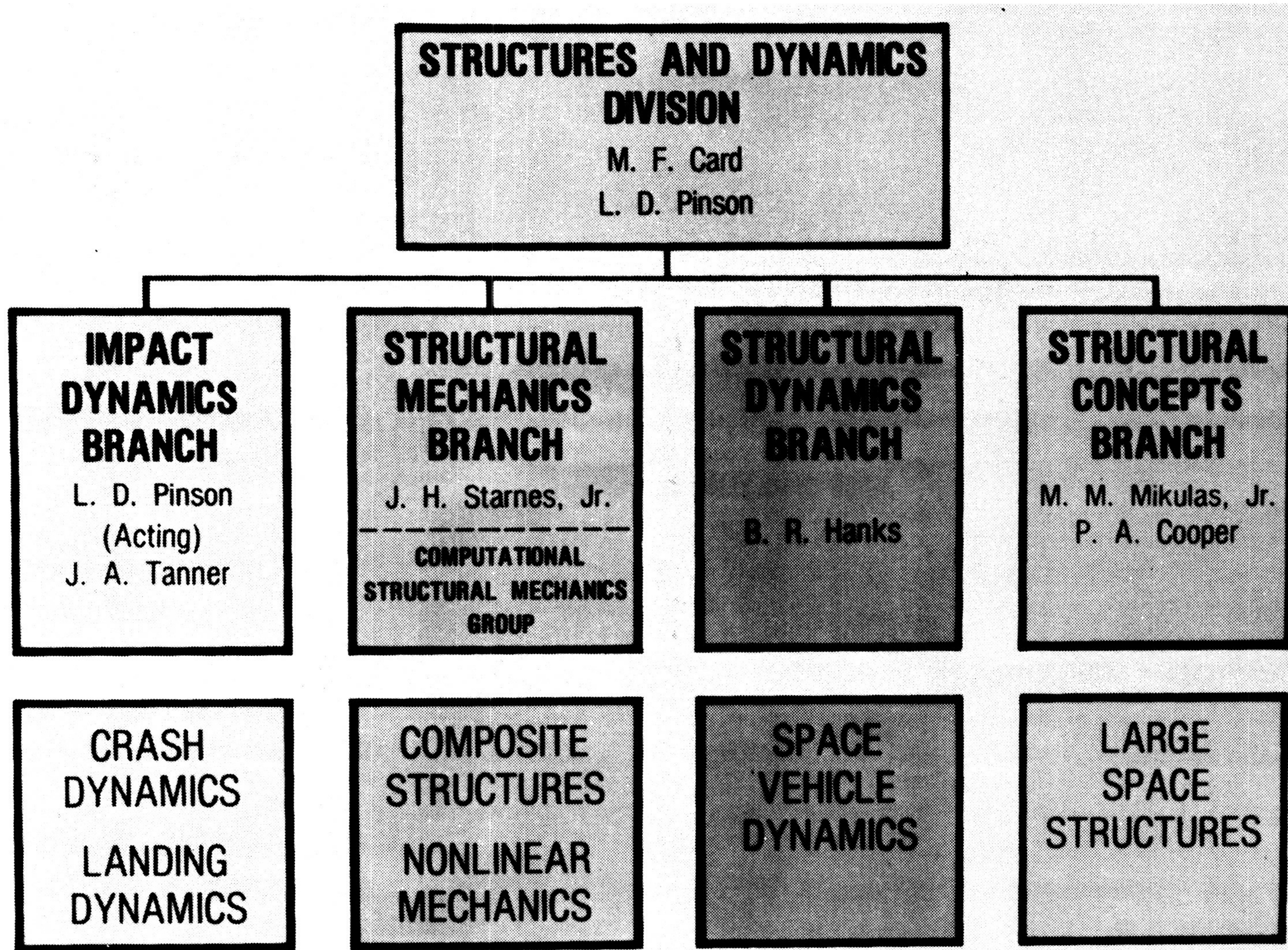
STRUCTURES AND DYNAMICS DIVISION
M. F. Card
L. D. Pinson
IMPACT DYNAMICS BRANCH
L. D. Pinson (Acting)
J. A. Tanner
STRUCTURAL MECHANICS BRANCH
J. H. Starnes, Jr.
COMPUTATIONAL STRUCTURAL MECHANICS GROUP
STRUCTURAL DYNAMICS BRANCH
B. R. Hanks
STRUCTURAL CONCEPTS BRANCH
M. M. Mikulas, Jr.
P. A. Cooper
CRASH DYNAMICS
LANDING DYNAMICS
COMPOSITE STRUCTURES
NONLINEAR MECHANICS
SPACE VEHICLE DYNAMICS
LARGE SPACE STRUCTURES

Figure 2.

II FACILITIES

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II FACILITIES

The Structures and Dynamics Division has four major facilities to support its research (shown in figure 3).

The Structures and Materials Laboratory equipment includes a 1,200,000 lb capacity testing machine for tensile and compressive specimens up to 6 feet wide and 18 feet long; lower capacity testing machines of 300,000, 120,000, 100,000 and 10,000 lb capacity; torsion machine of approximately 60,000 in.=lb capacity; combined load testing machine; hydraulic and pneumatic pressurization equipment; and vertical abutment-type backstop for supporting and/or anchoring large structural test specimens.

The Impact Dynamics Research Facilities consist of the Aircraft Landing Dynamics Facility (ALDF) and the Impact Dynamics Research Facility. The ALDF consists of a rail system 2,800 ft. long x 30 ft. wide, a 2.0 Mlbs. thrust propulsion system, a test carriage capable of approximately 220 knots, and an arrestment system. A wide variety of runway surface conditions, ranging from dry and flooded concrete or asphalt to solid ice, can be duplicated in the track test section. In addition, unprepared surfaces such as clay or sod can be installed for tests to provide data on aircraft off-runway operations.

The Impact Dynamics Research Facility is capable of crash testing full-scale general aviation aircraft and helicopters under controlled conditions. Simulation is accomplished by swinging the aircraft by cables, pendulum-style, into the ground from an A-frame structure approximately 400 ft. long x 240 ft. high. A Vertical Test Apparatus is attached to one leg of the A-frame for drop-testing structural components.

The Structural Dynamics Research Laboratory is designed for carrying out research on spacecraft and aircraft structures, equipment, and materials under various environmental conditions, including vibration, shock, acceleration, thermal and vacuum. Equipment in the laboratory includes a 55-ft. (inside diameter) thermal vacuum chamber with a removable 5-ton crane, a flat floor 70 feet from the dome peak, and whirl tables.

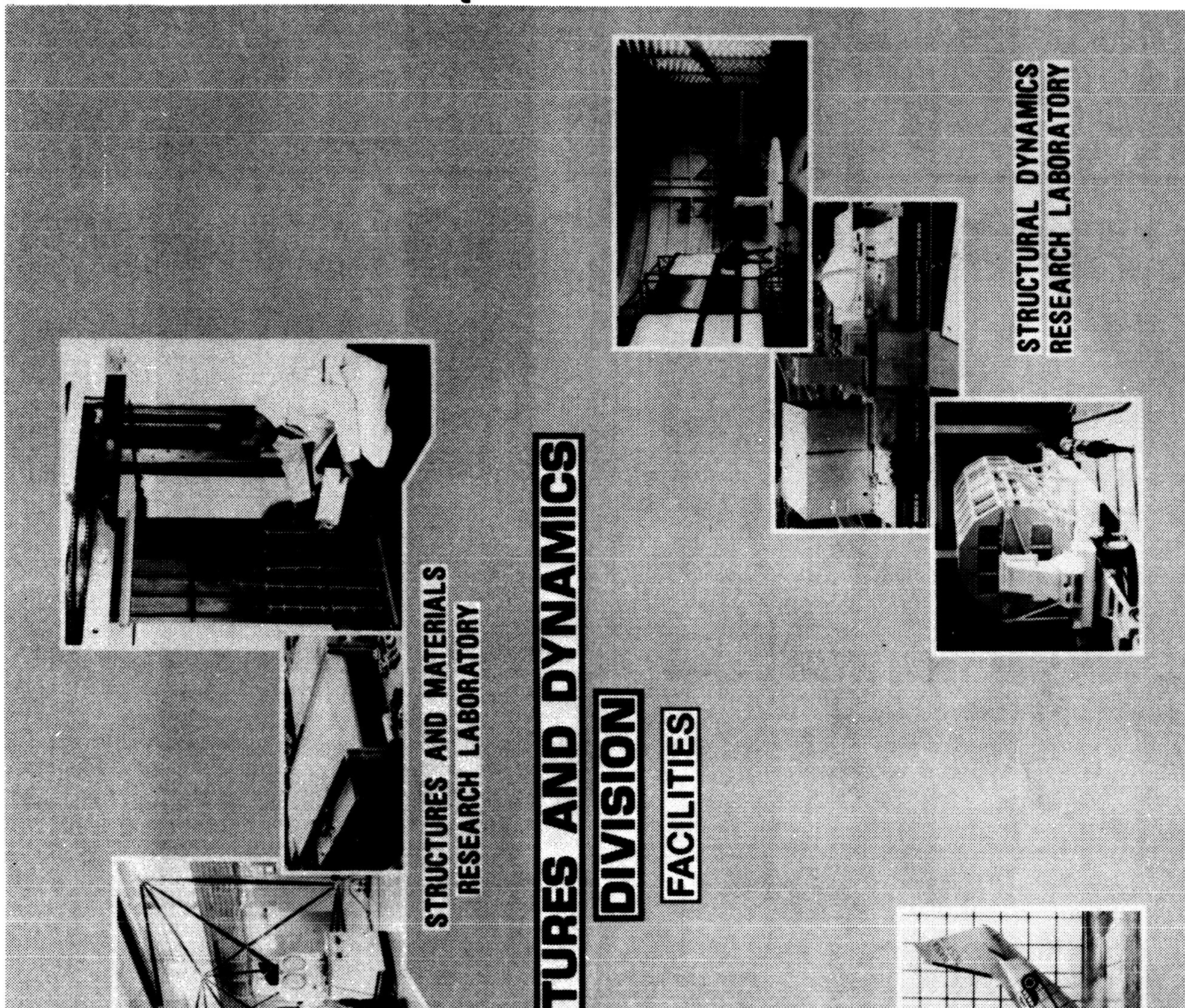
STRUCTURES AND DYNAMICS
DIVISION
FACILITIES
STRUCTURES AND MATERIALS
RESEARCH LABORATORY
STRUCTURAL DYNAMICS
RESEARCH LABORATORY
IMPACT DYNAMICS
RESEARCH FACILITIES

Figure 3.

III IMPACT DYNAMICS BRANCH

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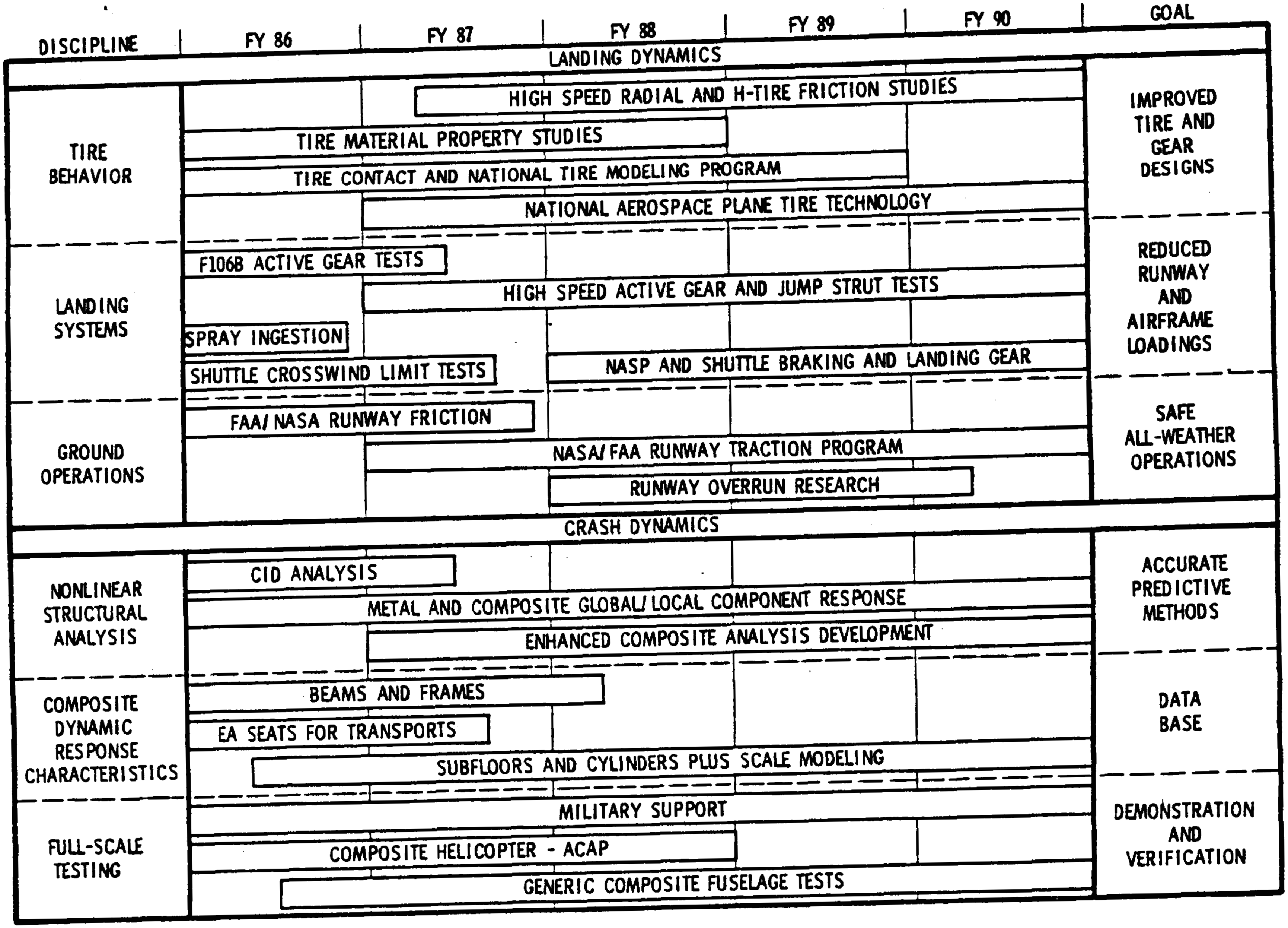
IMPACT DYNAMICS BRANCH



III IMPACT DYNAMICS BRANCH

RTR 505-63-11-06 Composite Crash Dynamics

OBJECTIVE:

To obtain a better understanding of response characteristics of generic composite components subjected to crash loading conditions.

FY 1987 PLANS:

- o Conduct analytical studies of various transport crash impacts
- o Conduct various static and dynamic tests of composite frames, subfloors, and energy absorber concepts
- o Initiate tests and analysis of scale model beams under impact loads
- o Develop analysis tools for composite crash dynamics
- o Support full-scale crash tests of ACAP helicopters

APPROACH:

In FY 1987 the main focus will be developing a data base and insights on behavior of composite components to crash loadings. Develop in-house test method, procedures, and apparatus to conduct static and dynamic combined bending and axial loading tests on representative composite structural elements. Assess impact data to evaluate effect of combined axial and bending loads on global response, stiffness and residual strength after failure and develop new analytical techniques to predict both global and local responses. Install these new algorithms on Computational Structural Mechanics software testbed. Supportive contractual efforts will be used mainly to fabricate composite components requiring special tooling.

MILESTONES:

- o Conduct metal subfloor water drop tests, November 1986
- o Conduct scaling studies on various composite beams, November 1986
- o Procure generic fuselage shells from Beech Aircraft and plan full-scale crash test matrix

- o Perform nonsymmetric analysis of CID using updated Boeing model, January 1987

- o Develop Analysis for predicting scale beam response to crash loads, January 1987

- o Develop intersection and crush initiator concepts for energy absorbing composite subfloors, March 1987

- o Initiate static testing and dynamic testing of intersection and crush initiator concepts, September 1987

FY 1986 ACCOMPLISHMENTS:

- o Published 7 papers on CID experiments

- o Fabricated scale beam specimens

- o Defined benchmark dynamic problems for scaled composite studies

- o Conducted tests and analysis on initial composite frames

- o Published summary paper on G/A seat research conducted at Langley Research Center

RTR 505-63-41-02 Aircraft Landing Dynamics

OBJECTIVE:

Advance the technology for safe, economical all-weather aircraft ground operations including the development of new landing gear systems.

FY 1987 PLANS:

- o Continue development of tire contact algorithms

- o Develop data base on radial and bias ply aircraft tires

- o Demonstrate active control landing gear technology

- o Develop friction and wear models for Shuttle main gear tires

- o Examine tire technology requirements for National Aerospace Plane (NASP)

APPROACH:

In FY 1987 the main focus will be developing high-speed frictional and mechanical property data base in support of industry and Shuttle landing operations. Coordinate in-house research, grants, and contracts with U.S. tire industry experimental effort to carry out National Tire Modeling Program. Conduct detailed studies of forces and moments in static and rolling tire footprints. Develop algorithms for tire contact to include friction and rolling tire footprints. Develop algorithms for tire contact to include friction and rolling effects for National Tire Modeling Program and install these algorithms on Computational Structural Mechanics software testbed. Develop experimental methods for measuring material properties of tire constituents. Define rational tire wear crosswind limits for Space Shuttle Orbiter. Obtain frictional and mechanical property data on type H and radial ply aircraft tires.

MILESTONES:

- Present paper on water spray ingestion at SAE AeroTech '86 Meeting, October 1986
- Publish paper on Space Shuttle Orbiter cornering and spin-up wear characteristics, December 1986
- Publish paper on tire contact algorithms, December 1986
- Conduct close range photogrammetry measurements of Shuttle nose gear tire deformations, February 1987
- Conduct track studies of F-4 raidal tires, March 1987
- Publish reports on NASA/FAA tire traction program, March 1987
- Measure forces and moments in rolling tire footprints, June 1987

FY 1986 ACCOMPLISHMENTS:

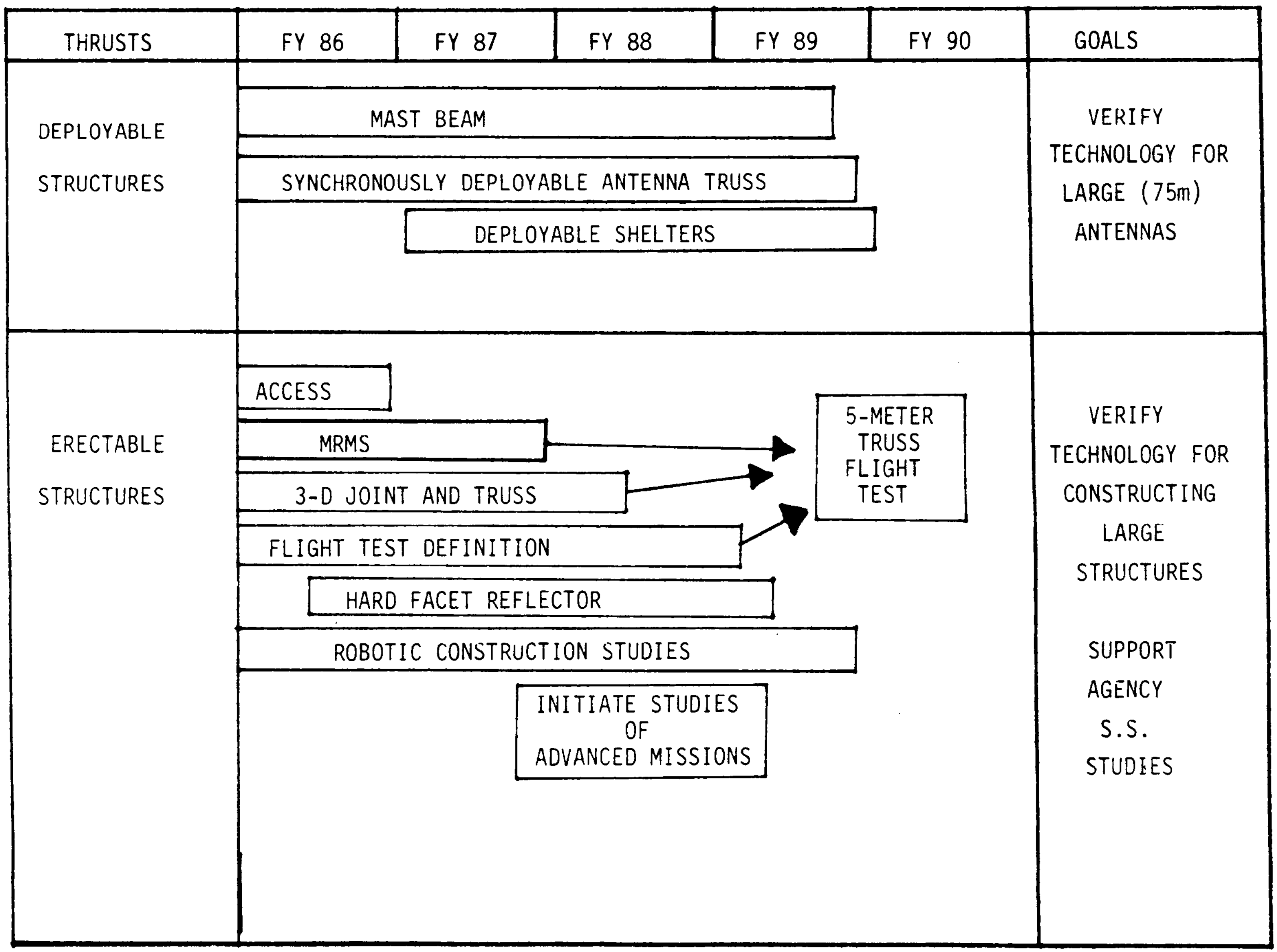
- Phase I Shuttle spin-up wear and cornering test completed and crew training simulators updated
- Paper on tilt steering presented at AeroTech '85 Meeting
- NASA/FAA snow and ice tests completed with B-727

- Session on Tire Modeling at Tire Society Meeting heavily supported by National Tire Modeling Program participants

- Completed spray ingestion tests on G/A nose gear tire

IV STRUCTURAL CONCEPTS BRANCH

ADVANCED SPACE STRUCTURES



IV STRUCTURAL CONCEPTS BRANCH

RTR 506-43-41-02 Advanced Space Structures Concepts

OBJECTIVE:

Develop deployable and erectable structural concepts and associated design technology for antenna and reflector structures and for Space Station.

FY 1987 PLANS:

- o 3rd generation joint design, fabrication and evaluation
- o Conceive MRMS for operation on curved surfaces
- o Develop space station construction scenario
- o Develop reflector truss construction scenario
- o Continue to support Mast program
- o Continue deployable reflector truss study
- o Develop deployable shelter

APPROACH:

In FY 1987 a major milestone will be the completion of a ground test Mobile Remote Manipulator System (MRMS) for conducting 1-g construction tests. The role of automation in the construction process will be investigated as part of this activity. Studies will continue on developing deployable trusses for antenna structures and a 36-element deployable test article will be fabricated. Efforts will continue on defining on-orbit construction scenarios and associated flight experiments.

MILESTONES:

- o Procure CAD terminals, October 1986
- o Complete ground test MRMS hardware, November 1986
- o 1-g test of MRMS, February 1987
- o Fabricate deployable 36-element truss model, March 1987

FY 1986 ACCOMPLISHMENTS:

- Conducted ACCESS flight test in November 1985
- Completed Erectable Joint Concept Study
- Designed and began fabrication of third generation erectable joint
- Influenced Space Station decision to baseline 5-meter erectable truss through an extensive trade study and the ACCESS flight experiment

RTR 481-32-23-02 Space Station Erectable Structures

OBJECTIVE:

Develop technology for a 5-meter composite truss for the Space Station. Develop and demonstrate a technique for constructing the truss from the Space Station.

FY 1987 PLANS:

- 3rd generation joint design, fabrication and evaluation
- Development of payload attachment fixtures
- Complete development of aluminum clad composite struts
- Fabricate and test 2 bays of composite truss hardware
- Fabricate and test 10-bay aluminum truss
- Studies to reduce EVA assembly hours

APPROACH:

In FY 1987 the main focus will be to identify suitable composite struts for the truss and to develop an on-orbit construction technique. Specifically, plans are to conduct an extensive study of various techniques for fabricating high stiffness, tough, graphite/epoxy struts and fabricate a 4-bay beam for testing. An in-house and contractual study will be conducted to develop and demonstrate an on-orbit construction approach.

MILESTONES:

- Define a structural flight experiment, December 1986
- Select composite strut design, March 1987
- Develop construction technique, March 1987
- Fabricate construction fixture, September 1987
- Fabricate 4-bay beam, September 1987

FY 1986 ACCOMPLISHMENTS:

- A second generation erectable joint with 3-D growth capability was designed and fabricated
- A full scale and 1/4-scale 7-bay beam was built for testing
- A third generation erectable joint was designed and is currently being fabricated
- Identified 20-bay beam as potential flight experiment

RTR 906-55-62-01 Flight Experiment Definition

OBJECTIVE:

- Provide integration support for the 5-meter erectable flight experiment with the Space Shuttle

FY 1987 PLANS:

- Continue flight experiment study

APPROACH:

An in-house and contractual effort will be conducted to integrate the 5-meter erectable flight experiment with the Space Shuttle system. The study will include hardware integration, EVA handling considerations, pallet mountings, and instrumentation integration. Detailed drawings of the hardware will be made and 1/8-scale and full-scale mockups will be built to verify the designs.

MILESTONES:

- o Complete flight experiment definition, November 1986
- o Initiate integration contract, December 1986

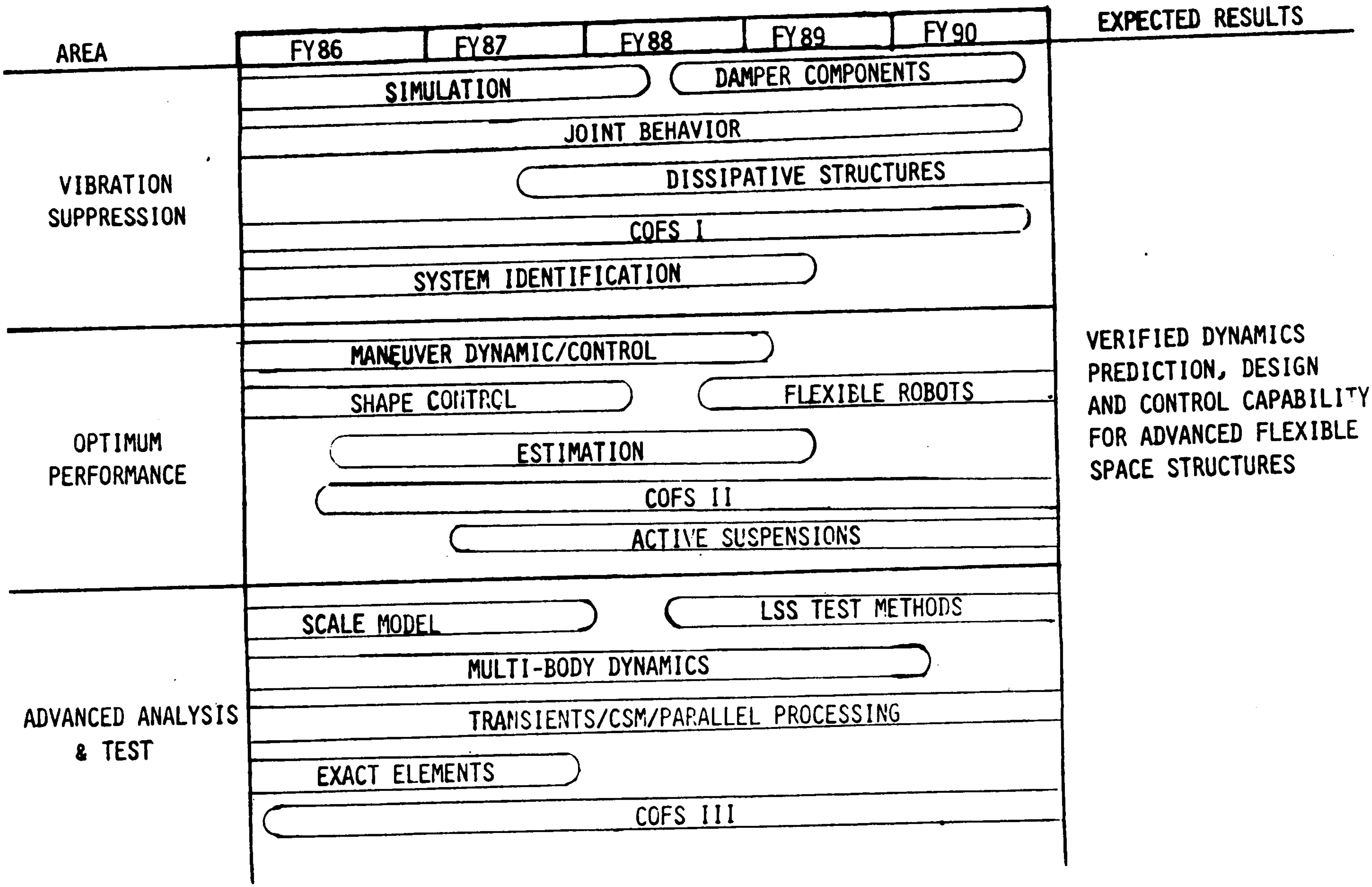
FY 1986 ACCOMPLISHMENTS:

- o 20-bay, 5-meter strut erectable truss identified as baseline for flight experiment
- o Preliminary in-house studies conducted on beam construction scenario, dynamic behavior, and orbital decay

V STRUCTURAL DYNAMICS BRANCH

STRUCTURAL DYNAMICS BRANCH

ACTIVITIES



V STRUCTURAL DYNAMICS BRANCH

RTR 506-43-51-01 Vibration Reduction

OBJECTIVE:

Accomplish validated capability for on-line structural parameter identification and active and passive vibration attenuation for large flexible space structures.

FY 1987 PLANS:

- o Conduct mini-Mast dynamics tests
- o Demonstrate 3-body slewing control
- o Develop recursive Eigensystem Realization Algorithm system identification method

APPROACH:

In FY 1987 the main focus will be the experimental verification of control and system identification techniques. The use of member actuators for reducing the response program will be conducted at both element and system levels using a truss beam as a focus. Physical elements such as joints, actuators, and electronic components will be analyzed individually and as parts of systems. Laboratory tests of hardware will be conducted to verify and improve analyses. Studies of advanced system identification algorithms which incorporate latest techniques into small-core, high-speed applications will be initiated. Completing tests of the 15M hoop-column antenna will be accomplished under this RTR.

MILESTONES:

- o Demonstrate 3-body closed-loop slewing control, December 1986
- o Complete dynamic tests of 15M hoop-column antenna, February 1987
- o Verified open-loop model of 20M truss beam including effects of joints, June 1987
- o Demonstrate closed-loop control of multiple-member-actuator truss-beam segment

FY 1986 ACCOMPLISHMENTS:

- Atmospheric effects in slewing experiments quantified
- Development of telescoping member truss beam segment initiated
- Frequency domain version of Eigensystem Realization Algorithm developed

RTR 506-43-51-02 Advanced Spacecraft Dynamics

OBJECTIVE:

Develop and validate methods for predicting and experimentally verifying the coupled structural dynamics and control of multi-body space structures with flexible components, interfaces, dissipative mechanisms and large amplitude responses.

FY 1987 PLANS:

- Begin 3-D LATDYN
- Integrate 2-D LATDYN into Computational Structural Mechanics

APPROACH:

In FY 1987 the main focus will be the continuation of development of a three-dimensional computerized simulation of controlled dynamics of multi-body flexible space structures as encountered in deployment, slewing and robotic arm manipulation. Included in this thrust is the development of improved modularized transient algorithms for concurrent computing, and realistic verified models for joint and interface damping mechanisms. In addition, advanced slewing control analyses will be studied and test suspension methods for large space structures will be analyzed.

MILESTONES:

- Establish computational approaches for analyzing nonlinear contact and sliding dynamics in spacecraft interfaces, December 1986
- Incorporate nonlinear truss joint characterization in transient response of space station keel truss, January 1987

FY 1986 ACCOMPLISHMENTS:

- o Multi-body synthesis of generic space station model completed
- o Preliminary dynamic behavior of suspended space station scale model established
- o Controls and berthing capability incorporated into 2-D LATDYN
- o Nonlinear joint characterization documented
- o Substructuring capability installed in BUNVIS
- o Computerized procedure for discretely changing constraints developed and documented

RTR 542-06-11-06 Beam Dynamics Ground Test

OBJECTIVE:

Validate ground tests technology and conduct tests necessary to demonstrate flight readiness for the Mast experiment.

FY 1987 PLANS:

- o Test COFS-I 20M prototype and components

APPROACH:

In FY 1987 the main focus is the development of test methods and suspension techniques for the Mast using a 20M truss beam (mini-Mast). Analytical methods of including joint characteristic and suspension dynamics in a global dynamics model will be evaluated. Measured global dynamic characteristics of the mini-Mast will be predicted using state-of-the-art techniques. Evaluation of suspensions for the 60M test will begin. Assembly and checkout of a portable data acquisition system for the flight article ground tests will be completed.

MILESTONES:

- o Complete outfitting of mobile data acquisition trailer, December 1986
- o Begin modifications to Hangar Annex for ground tests, February 1987

- o Initiate study of candidate suspensions for flight beam, March 1987
- o Complete modal test on 20M mini-Mast, June 1987
- o Complete joint characterization tests, August 1987

FY 1986 ACCOMPLISHMENTS:

- o Mini-Mast joint tests begun
- o Preliminary analytical models developed
- o Mobile data acquisition system definition completed

RTR 542-06-31-01 COFS III Technology

OBJECTIVE:

Develop structural dynamics technology for COFS III ground and flight experiments.

FY 1987 PLANS:

- o Release RFP for Space Station scale model design and fabrication

APPROACH:

In FY 1987 the main focus will be on initiating a contract for the design and construction of the COFS III ground experiment model which will be Space Station oriented in anticipation of on-orbit flight data. Analysis and test methods for the dynamics and control of multiple-component, joint-dominated structures will be emphasized. Desired model characteristics as well as fabrication requirements and capabilities will be developed. In related technology, studies of the scaling of model components such as tubular members and structural joints will be continued and in-huse tests and analyses of prototype space station hardware will be conducted. A phenomena model to examine test and analysis methods for the COFS III candidate configuration structure will be designed and fabricated.

MILESTONES:

- o Complete tests of 1/4-scale space station, November 1986
- o Complete design of phenomena model, January 1987

- o Complete tests of full-scale space station truss model, June 1987

- o Award contract for scale model design/construction, August 1987

FY 1986 ACCOMPLISHMENTS:

- o Preliminary model feasibility study contract completed
- o Study of joint scaling/analysis initiated
- o Ground tests of 1/4-scale erectable truss initiated
- o Model definition study contract awarded
- o Phenomena model design study initiated
- o Statement of work for scale model design/fabrication contract under development
- o Prototype scale model composite parts and structural joints received and testing under way

RTR 482-53-53-38 Space Station Model Definition/Design

OBJECTIVE:

Develop a sub-scale replica model technology for space station applications and a methodology for its use in dynamic development and qualification.

FY 1987 PLANS:

- o Procure and test 1/10-scale generic dual keel station
- o Perform pre-test analytical studies for replica model

APPROACH:

In FY 1987 the main focus will be on defining requirements for and designing the model and on defining roles, procedures and test methods for use of such a model in space station development. A replica model of the Space Station of approximately one-fourth to four-tenths scale will be defined for use in predicting space station on-orbit dynamics. Test suspension, excitation and instrumentation methods will be studied. Initial efforts will be on development and tests of an IOC configuration in time to

assist space station CDR. Scar effects on the IOC configuration resulting from advanced configurations also would be determined. These funds will be combined with design/construct contract on RTR 542-06-31-01.

MILESTONES:

- Initiate definition study contract for a replica model, January 1987
- Initiate study of suspension and test methods, April 1987

FY 1986 ACCOMPLISHMENTS:

- Model feasibility study completed

RTR 483-32-33-03 Flexible Body Deployment Analysis Development

OBJECTIVE:

Develop, early in the space station program, verified analytical capability required for space station construction, maneuvers, berthing and robotic arm manipulation.

FY 1987 PLANS:

- Initiate coding of 3-D articulation code
- Perform 2-D simulation studies on station operations (e.g., robotic arm maneuver)

APPROACH:

In FY 1987 the main focus will be the continued incorporation of new technology analytical methods into usable computer programs which can aid the space station project in systems engineering and integration. Emphasis is on a convected coordinate approach for treating connected flexible components in problems such as automated assembly.

MILESTONES:

- Establish prototype 3-D LATDYN code, September 1987

FY 1986 ACCOMPLISHMENTS:

- 2-D LATDYN theory documented
- 2-D LATDYN User Manual completed

- 2-D LATDYN enhancements for berthing and controls completed
- 3-D LATDYN coding contract initiated

VI STRUCTURAL MECHANICS BRANCH

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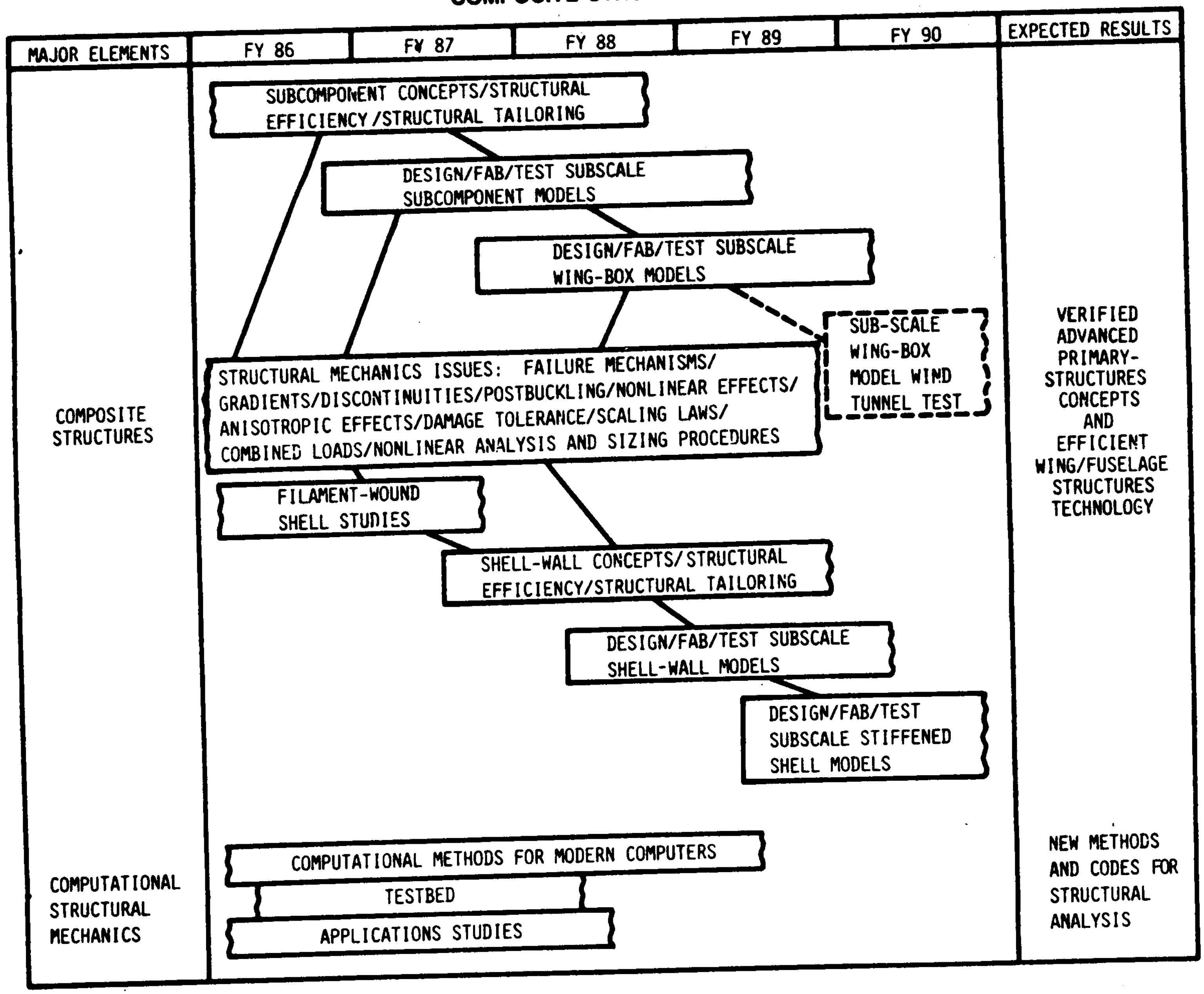
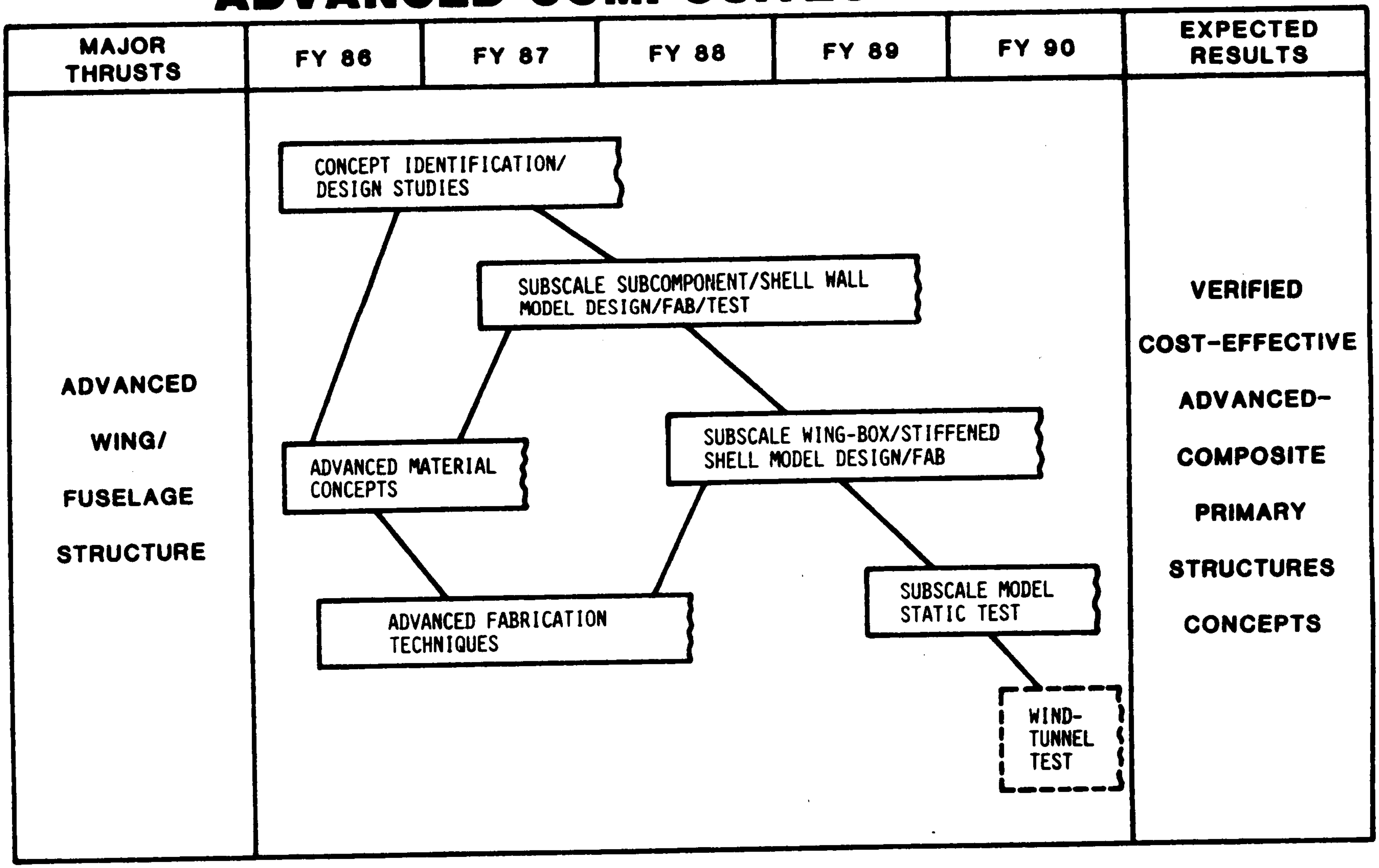
STRUCTURAL MECHANICS

COMPOSITE STRUCTURES



ADVANCED COMPOSITES PROGRAM



VI STRUCTURAL MECHANICS BRANCH

RTR 505-63-11-03 Mechanics of Composite Structures

OBJECTIVE:

Develop mechanics technology required for verified design of efficient, fault-tolerant advanced-composite airframe structural components and to formulate advanced analysis methods to predict ultimate strength of composite structures and static and dynamic nonlinear response to aerospace structures.

FY 1987 PLANS:

- o Complete development of nonlinear modal interaction analysis
- o Initiate development of scaling laws for composite structures
- o Complete nonlinear analysis of filament-wound solid rocket booster

APPROACH:

In FY 1987 the main focus is verifying new failure analysis for compression-loaded multi-directional laminates and on implementing into STAGS an in-house-developed nonlinear modal interaction analysis for built-up components.

MILESTONES:

- o Initiate development of scaling laws for composite structures, October 1986
- o Verify failure analysis for compression-loaded multi-directional laminates, February 1987
- o Complete test-analysis correlation of stiffened filament-wound cylinder and heavily-loaded side-of-body wing joint, April 1987
- o Complete development of error analysis for nonlinear plates using recontinuization method and extend method to include transverse shear and normal stresses, May 1987
- o Conduct nonlinear analysis of filament-wound solid rocket booster, June 1987

FY 1986 ACCOMPLISHMENTS:

- Effects of cutouts on postbuckling behavior of unstiffened graphite-epoxy shear webs identified experimentally
- Crippling strength of compression-loaded multi-directional laminates determined by a nonlinear analysis
- Both thickness and stiffness discontinuities shown to effect compressive strength of graphite-epoxy laminates with dropped plies
- Tests and analyses show that increasing cutout size does not necessarily decrease the buckling strength of compression-loaded composite plates
- Non-optimum filament-wound graphite-epoxy stiffened cylinder tested. Analysis being conducted to help identify failure mode
- New high-order transverse-shear plate analysis shows that plates with low width-to-thickness ratios buckle at loads below those for classical transverse shear theory
- Nonlinear modal interaction analysis for plates developed. Analysis being implemented in a general purpose nonlinear shell code for general shells

RTR 505-63-11-05 Advanced Composite Structural Concepts

OBJECTIVE:

Develop verified composite structural concepts and design technology needed to realize the improved performance, structural efficiency, and low-cost advantages offered by new material systems and manufacturing methods for advanced-composite aircraft structural components.

FY 1987 PLANS:

- Complete initial anisotropic tailoring studies of high-aspect-ratio laminar-flow wings
- Continue development and evaluation of new structurally-efficient composite panel concepts
- Conduct damage-tolerance tests of new graphite-epoxy panel concepts

- Continue studies of structural tailoring and interleaving for stiffened panels

APPROACH:

In FY 1987 the main focus is developing new structurally-tailored wing component design concepts and evaluating the performance of low-cost filament-wound structural concepts. Innovative structural configurations for advanced aircraft applications will be developed and evaluated for improved performance, structural efficiency, and damage tolerance. The effects of constraints, such as those imposed by aero-elastic tailoring, laminar flow, acoustics and control, will be included in the design of new structural concepts for aircraft components. Mechanical and pressure loads representative of wing and fuselage structural components will be considered. Associated structural mechanics issues peculiar to these new design concepts will be studied and selected concepts will be evaluated experimentally.

MILESTONES:

- Experimentally evaluate preliminary design of geodesic stiffened compression panel, October 1986
- Conduct damage tolerance tests of graphite-epoxy filament-wound and sandwich panels, February 1987
- Initiate fabrication of transport wing box beam concept, April 1987
- Experimentally evaluate two additional new advanced compression panel concepts, April 1987
- Complete initial anisotropic tailoring study of high-aspect-ratio laminar-flow wing, June 1987
- Complete design study of optimum tapered wing-box with new panel concepts and damage tolerance considerations, June 1987
- Conduct design and analysis studies of advanced concept tapered spars and cover panels and fabricate sub-components, September 1987

FY 1986 ACCOMPLISHMENTS:

- Open-hole compressive strength of thermoplastic laminates shown to be slightly lower than for epoxy laminates

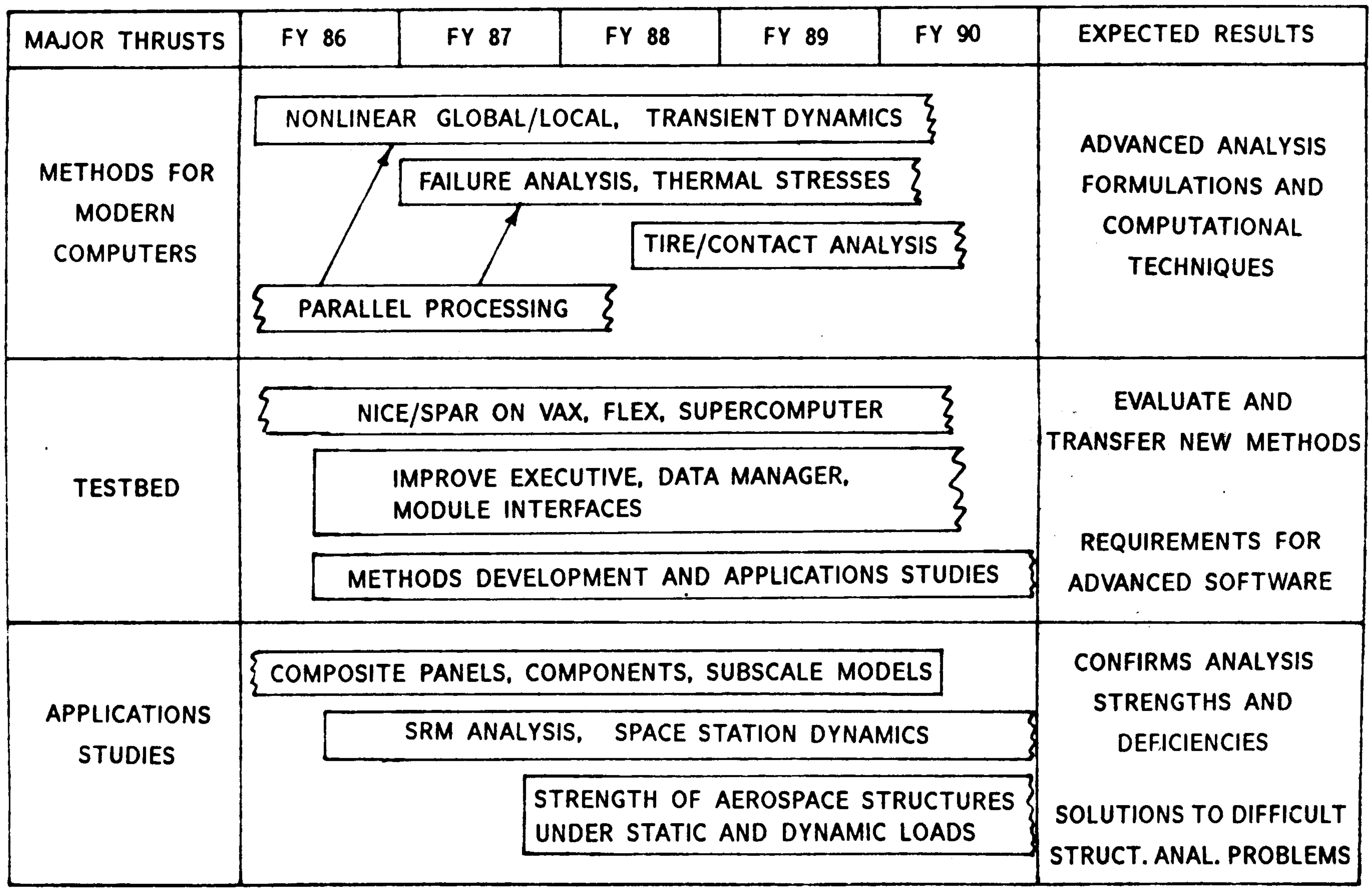
- Fiberglass edge reinforcements and in-plane tapered insert reinforcements shown to increase compressive and tensile strength of graphite-epoxy plates with holes

- Preliminary design of high-aspect-ratio swept-forward wing with laminar flow airfoil shows that structural tailoring with graphite-epoxy materials can provide minimum weight wings with no twist at ultimate load
- Weight/cost analysis identifies new composite panel concepts that are both lighter in weight and lower in cost than conventional aluminum stiffened fuselage panels

- Designed and fabricated advanced high-aspect-ratio cover panel concept using damage-tolerant interleaved materials. Testing to evaluate concept is under way

- Baseline and alternate wing panel and spar concepts evaluated for transport wing box beam

COMPUTATIONAL STRUCTURAL MECHANICS
FIVE YEAR PLAN



RTR 505-63-11-07 Computational Structural Mechanics

OBJECTIVE:

Develop advanced structural analysis and computation methods that exploit advanced computer hardware and develop standard generic software system for structural analysis.

FY 1987 PLAS:

- o Award task assignment contracts for testbed, methods research, and applications studies
- o Demonstrate capability for routine nonlinear global/local analysis of composite structures
- o Demonstrate UNIX version of CSM testbed on NAS for large finite element problem
- o Integrate parallel equation solvers into CSM testbed and demonstrate on FLEX or NAS
- o Demonstrate parallel dynamic analysis

APPROACH:

In FY 1987 the main focus will be upgrading initial testbed (NICE/SPAR) and developing analysis capability for multi-processor computers. Methods research will emphasize procedures that exploit computers having multiple processors and a concurrent processing capability. To aid in the methods development research, a testbed system will be created. It will consist initially of software for Langley's VAX and Cyber computers and a combination of software and hardware for concurrent processing. A standard generic software system that can accept applications modules will be developed. This software system will be aimed at the computers and aerospace structural analysis problems of the late 1980's and beyond.

MILESTONES:

- o Award task assignment contracts for analysis testbed, methods research, and applications studies, October 1986
- o Demonstrate parallel equation solver and parallel eigenvalue solver in NICE/SPAR, December 1986
- o Demonstrate geometric nonlinear finite element capability of NICE/SPAR on multiprocessor computer, March 1987

- Demonstrate UNIX version of NICE/SPAR on NAS for large finite element problem, March 1987
- Demonstrate capability for routine global/local analysis of composite structures, July 1987
- Demonstrate error analysis capability on composite subscale problem, September 1987
- Develop transient algorithms for multiprocessor supercomputers, September 1987

FY 1986 ACCOMPLISHMENTS:

- Converted NICE/SPAR testbed to UNIX; installed on single and multiple processors of FLEX
- Installed shear flexible elements, geometric nonlinearity, and laminate utility in NICE/SPAR
- Documented study of error analysis techniques
- Documented study of global/local stress analysis for composite panel with discontinuous stiffener
- Parallel Lanczos eigensolver demonstrated to be efficient on FLEX

RTR 506-43-41-04 SRB Joint Concept Study

OBJECTIVE:

This RTR is to conduct an independent assessment of design procedures for development of a SRB (Solid Rocket Booster) joint fix; and to evaluate alternate design fixes. To set up analyses of SRB deformations using advanced analysis tools; and to investigate alternate concepts using experience in gas leak problems in wind tunnels and flight vehicles. The effort reported herein are the results of a team effort by personnel of the Structures and Dynamics Division, Materials Division, and Systems Engineering Division.

MILESTONES:

- o Initial request to investigate field joint concepts, February 1986
- o Complete assessment of MSFC (Marshall Space Flight Center) concepts, May 1986
- o Complete development of LaRC (Langley Research Center) alternate concept, August 1986
- o Participate in SRM Preliminary Design Review, September 1986

FY 1986 ACCOMPLISHMENTS:

<u>Structural Concepts</u>

- o Developed and analyzed alternate bolted design concept for SRB joints

<u>SRM Analysis</u>

- o Developed 3-D models of 51-L joint and correlated with reference test
- o Identified pin hole clearances as key parameters in clevis-tang joint analyses
- o Performed inelastic 3-D analyses of 51-L joints showing residual plastic deformations under proof load
- o Developed 3-D analysis of interference fit capture tang design
- o Developed SRM shell model

O-Ring Studies

- o Developed resiliency data for various temperature levels on candidate seal materials

- o Developed test fixtures and provided dynamic sealing and failure data to MSFC on candidate materials

Thermal Design

- o Developed concepts for sealed thermal insulation of field joints

- o Performed thermal analyses of sealed and vented cavities to determine effects of cavity configuration

VII ACCOMPLISHMENT HIGHLIGHTS

IMPACT DYNAMICS BRANCH

GENERIC COMPOSITE FUSELAGE FRAME IMPACT STRAIN DISTRIBUTION MEASURED AND COMPUTED

Richard L. Boitnott and Huey D. Carden
Impact Dynamic Branch
Extension 3795   May 1986
RTOP 505-63-41   WBS 25-1

Research Objective

Impact tests of generic composite structural components are part of research addressing the global response and behavior of such structure to typical crash loadings. The objective of the present study is to develop an understanding of the dynamic response of composite fuselage frames under crash loadings.

Approach

For test specimens, 6-foot diameter Z-cross-section circular frames were fabricated from graphite epoxy drapable fabric material. Opposite sides of the frame were tied together with a beam and lead ballast was added to the structure/beam intersections to represent partial loads of seat/occupants. The composite frames were impacted onto concrete at approximately 25 fps vertical velocity in a drop tower apparatus. The apparatus maintained the frame in a vertical plane during free-fall and subsequent impact similar to the constraints of stringers and/or interior cover sheets in aircraft fuselages. Responses and behavior of the composite frame during the impact were recorded with accelerometers, strain gages, and high speed motion pictures.

Accomplishment Description

The attached figure compares measured and computed strain distributions on the outside flange of the composite Z-frame at 4.8 msec after impact just prior to failure of the frame. The frame was modeled with the DYCAST structural analysis computer code using Z-shaped beam elements with laminate properties of the composite frame. A maximum strain-to-failure criteria was used to specify failure strain (+/-6400 microin/in) in the beam elements. Comparisons indicate agreement in the general shape of the strain distribution; however, experimental strains near the splice plate are lower than analytical strains. The failure of the frame occurred at about 15 degrees from the impact point in both the analysis and the test. A finer modeling of the frame in the impact region where large strain gradients are occurring may improve the correlation.

Significance

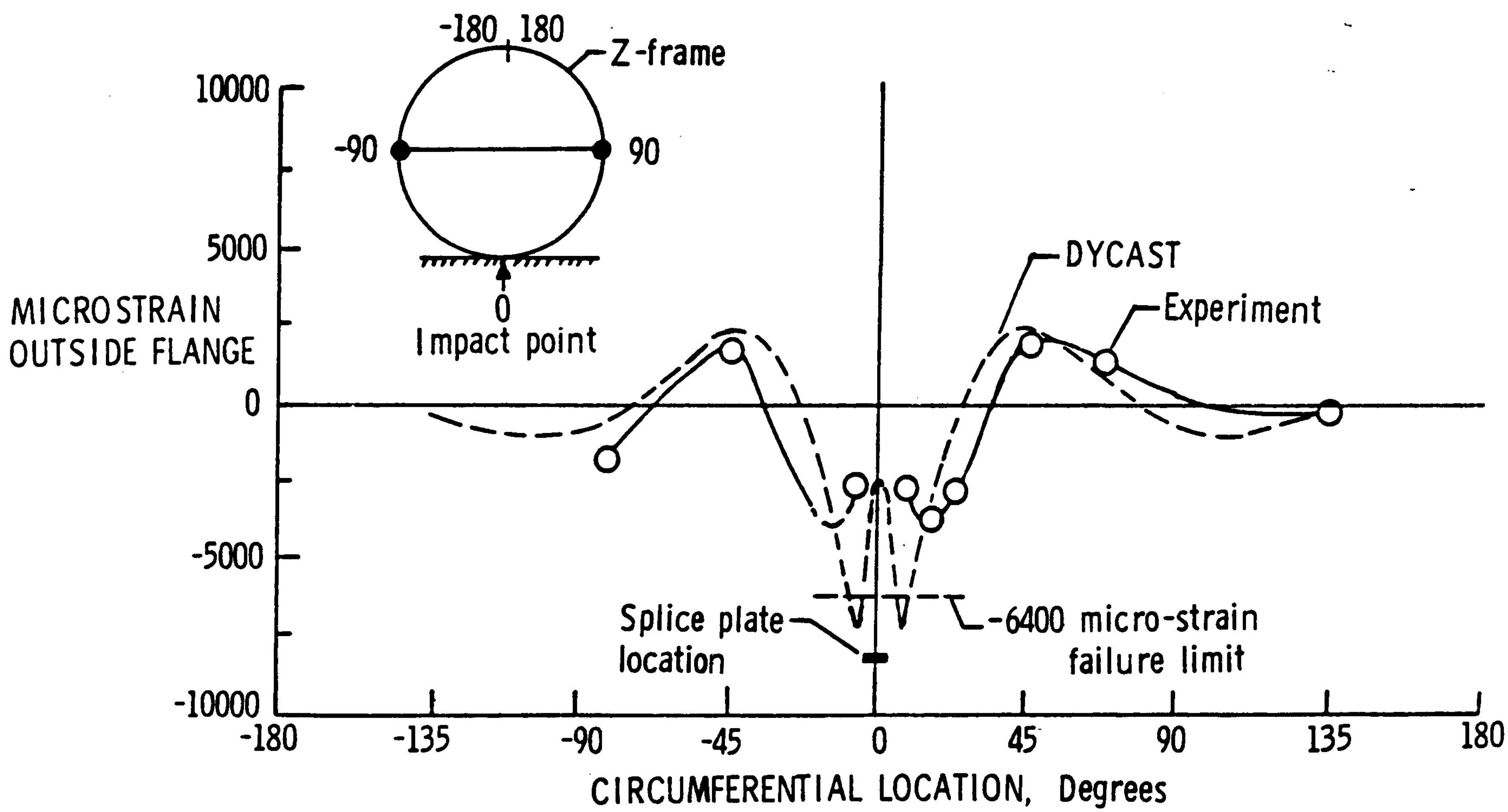
Data from frame tests should provide insight into the global response/behavior of more complex structures such as composite subfloor structures.

Future Plans

Additional composite fuselage Z-frames will be tested and refinements made to the DYCAST model for assessing the response and failure of these typical structural components under crash loadings. A paper entitled "Drop Testing and Analysis of Six-foot Diameter Graphite-Epoxy Frames" will be presented at the AHS National Specialists' Meeting on Crashworthy Design of Rotorcraft on April 7-9, 1986 in Atlanta, Georgia.

COMPOSITE FRAME STRAIN DISTRIBUTION

TIME = 4.8 MSEC AFTER IMPACT



TECHNICAL HIGHLIGHT

WATER SPRAY GENERATED BY AIRCRAFT NOSE TIRES MEASURED IN DETAIL IN UNIQUE TEST FACILITY

Robert Daugherty and Sandy Stubbs
Impact Dynamics Branch
Ext. 2796

October 1985

RTOP 505-63-41

Code RM WBS 25-2

Research Objective

Some aircraft experience engine problems and/or flameouts due to spray from the nose wheel(s) being ingested when operating on flooded runways. This can be especially dangerous if the problems occur during takeoff. The objective of the NASA Langley spray ingestion research is to define the trajectory and measure the flow rate of spray from an aircraft nose tire under various conditions.

Approach

To better define the volume and distribution of water being displaced by a nose tire, a spray measurement technique was developed at LaRC. Tests were conducted in the Hydrodynamics Research Facility in which a nose gear was attached to the electrically driven carriage, and an array of tubes was installed on the carriage to collect the spray produced when the nose tire engaged a flooded runway.

Accomplishment Description

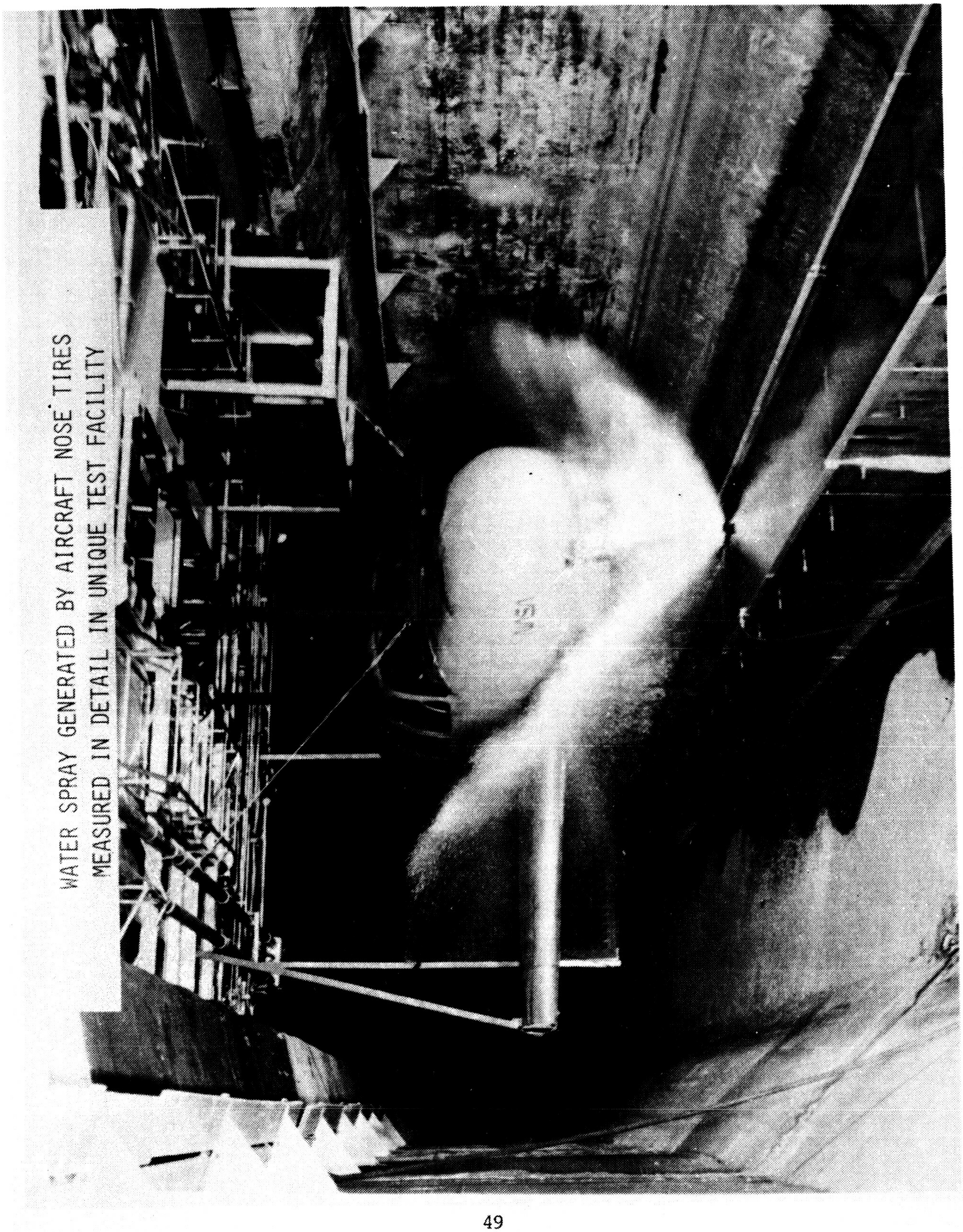
Tests have been conducted at speeds of up to 80 fps, at water depths from 1/4 to 5/8 in., and with vertical loads ranging from 500 to 2500 lb. The water collection system, a 484 tube array, has proven to be a simple yet accurate means of obtaining data. After a test run, the water in each tube was measured and recorded. The collector can be positioned anywhere aft of the nose gear and surveys have been conducted at various planes perpendicular to the direction of motion. A general aviation, twin-engine aircraft fuselage and wing were mounted under the carriage to investigate the aerodynamic effects of the airplane structure on spray trajectory. In addition, tests were conducted to determine if there is a difference in the spray patterns generated by a conventional bias-ply DC-9 nose tire versus one of radial construction.

A number of observations have been made during the research so far. The water leaves the tire footprint in a sheet as opposed to a jet (see in the enclosed photograph). The spray picks up a forward ground speed but significantly less than expected. The bow wave in front of the tire acquires a forward ground speed higher than that of the wheel but atomizes very quickly and contributes very little to the water that could be ingested into an engine. As the tire passes through a flooded runway, a wake is left much the same as from a boat. This wake, like the tire, has enough energy to throw water into the air, so that a much larger volume of water, perhaps as much as 5-10 times greater than that displaced by the tire footprint alone, is displaced and may eventually find its way into the engine.

No measurable difference in spray patterns were present in the DC-9 nose tire tests conducted with bias-ply and radial tire construction. This conclusion may eliminate the need for costly recertification of U.S. commercial transport aircraft using radial tires. The present series of spray ingestion tests have been completed and will be reported in a NASA TP.

Future Plans

Future spray ingestion tests are being considered for the newly operational ALDF.


WATER SPRAY GENERATED BY AIRCRAFT NOSE TIRES
MEASURED IN DETAIL IN UNIQUE TEST FACILITY

TECHNICAL HIGHLIGHT

AIRBOAT STUDIES SHOW COROTATION EFFECT ON TILT STEERING

Robert H. Daugherty
Sandy M. Stubbs
Impact Dynamics Branch
Ext. 2796 January 1986
RTOP 505-63-41
Code RM WBS 25-2

Research Objective

To determine the cause of the tilt steering phenomenon and to define the effects of various parameters on the cornering forces generated by tilted aircraft tires.

Approach

Tow tests were conducted using a modified airboat previously used for air cushion landing gear research. The vehicle was equipped with a tricycle landing gear and towed while in a tilted attitude. Measurements of the cornering forces produced by the nose tire in a variety of configurations were made.

Accomplishment Description

A number of tests were conducted to determine the reason for the generation of cornering force by a tilted tire. It was found that a tilt angle causes one side of the tire to have a smaller rolling radius than the other side. Consequently, when the tire rolls, one side of the tire footprint produces braking slip while the other side ac- tually produces driving slip. This differential slipping creates a torque in the tire footprint which yaws the tire and causes it to produce an uncommanded steering force, particularly if the nose gear is free to swivel. Although significant forces can be developed by a single tire, one of the more dramatic effects occurs if a nose gear is comprised of two tires locked together so they must turn at the same angular velocity, or corotate. The figure shows the effect of corotation on the sensitivity of the cornering force coefficient as a function of tilt angle. Cornering force coefficient is defined as the cornering force divided by the vertical load on the tire. The figure shows that a corotating twin-tire system produces much larger coefficients than a twin-tire system whose tires can rotate independently. At about five degrees, the tilt angle was severe enough to cause one of the tires to begin leaving the ground. At about eight degrees, one tire was completely free of the ground, causing the corotating system to behave as a single tire. Earlier tests showed that an independently rotating twin-tire system produced the same coefficients as a single-tire system. It should be noted that the Space Shuttle orbiter nose gear is a corotating twin-tire system which can produce these more dramatic uncommanded cornering forces if the nose gear is free to swivel and the orbiter becomes tilted on the runway.

Future Plans

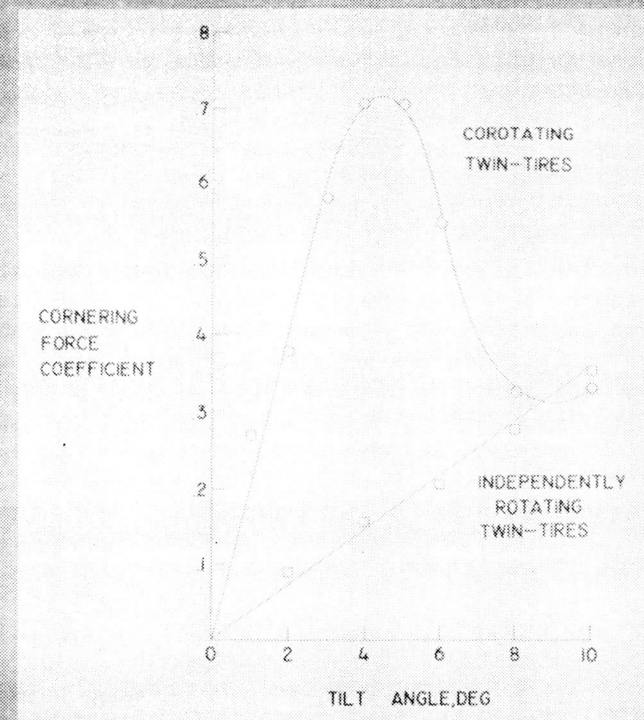
Tests are scheduled to be conducted at high speeds using the new Aircraft Landing Dynamics Facility. These tests would use larger tires than used in the present investigation to better define aircraft tire tilt steering behavior.

NASA
L-85-12,928

AIRBOAT STUDIES SHOW COROTATION EFFECT ON TILT STEERING

TEST VEHICLE

EFFECT OF COROTATION



TECHNICAL HIGHLIGHT

TEST VEHICLE STUDIES SHOW FOOTPRINT ASPECT RATIO EFFECT ON TIRE HYDROPLANING SPEED

Thomas J. Yager
Impact Dynamics Branch
Ext. 2796 February 1986
RTOP 505-63-41-02
Code RM WBS 25-2

Research Objective

To define effect of highway vehicle tire footprint aspect ratio (footprint width divided by length) on the hydroplaning inception speed.

Approach

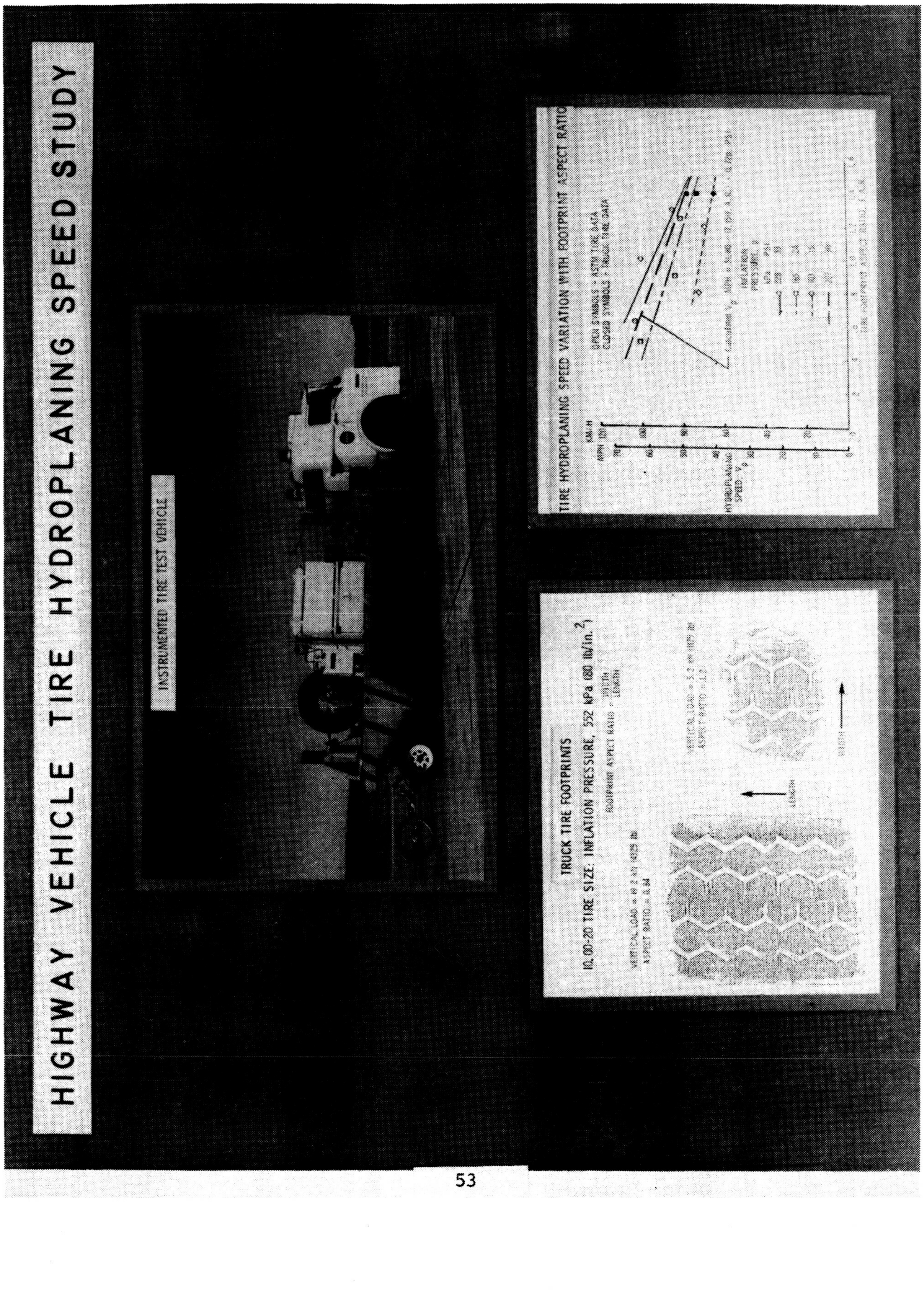
Constant speed tests were conducted using the instrumented tire test vehicle shown in the figure equipped with ASTM E-501 grooved and E-524 smooth automotive tires on flooded surfaces at NASA Wallops Flight Facility. A variety of tire inflation pressures and vertical loads produced a large range of tire footprint aspect ratios for evaluation under free and yawed rolling test conditions. Test tire speeds and forces developed during vehicle runs up to 105 km/h (65 mph) were monitored on the flooded test surface to identify development of tire hydroplaning phenomenon.

Accomplishment Description

Recent investigations of highway vehicle tire hydroplaning behavior reveal that in addition to inflation pressure, tire footprint aspect ratio has a significant influence on the dynamic hydroplaning inception speed. A variety of tire tests on flooded surfaces through a range of speeds, inflation pressures, and vertical loads have been conducted using the instrumented tire test vehicle. As shown in the figure, highway vehicle tire footprints differ from aircraft tire footprints in that the width dimension remains nearly constant for different loading conditions whereas for aircraft tires, both footprint dimensions vary with loading resulting in a relatively small range of aspect ratio values. Based on both ASTM automotive tire tests conducted by NASA Langley and truck tire tests conducted by the Texas Transportation Institute, an empirical equation has been formulated to predict highway vehicle tire hydroplaning speed. This equation predicts that hydroplaning speed decreases with increasing footprint aspect ratio (FAR) whereas the initial tire hydroplaning speed equation, which was derived earlier from NASA aircraft tire data, is a function of inflation pressure only. During wet weather, highway vehicle operators are cautioned to be alert to the possibly lower hydroplaning speeds due to the influence of tire footprint aspect ratio effects when their vehicles are lightly loaded.

Future Plans

Additional highway vehicle tire tests are planned to refine and substantiate this tire hydroplaning speed dependence on footprint aspect ratio. These tests will evaluate an expanded footprint aspect ratio range and permit assessment of other parameters such as net bearing pressure and tire construction on hydroplaning inception speed.


HIGHWAY VEHICLE TIRE HYDROPLANING SPEED STUDY
INSTRUMENTED TIRE TEST VEHICLE
TIRE HYDROPLANING SPEED VARIATION WITH FOOTPRINT ASPECT RATIO
TRUCK TIRE FOOTPRINTS
10.00-20 TIRE SIZE; INFLATION PRESSURE, 552 kPa (80 lb/in.2)

SPACE SHUTTLE ORBITER MAIN LANDING GEAR TIRE SIDE FORCE FRICTION MODEL DEVELOPED

Sandy M. Stubbs and Robert H. Daugherty
Impact Dynamics Branch
Ext. 2796 April 1986
RTOP 505-63-41 CODE RM WBS 25-2

Research Objective
The objective of this research is to define side force friction characteristics of the Space Shuttle Orbiter main gear tires for a computer model to be included in shuttle simulators used to train astronauts for landing rollout and to initiate a national tire friction data base for high speeds and high loads.

Approach
Tire cornering tests were conducted on the updated Aircraft Landing Dynamics Facility (ALDF) to determine effects of yaw or steering angle, tire vertical load, and speed on side force friction coefficient behavior of orbiter main gear tires. A multiple linear regression analysis was used to obtain an equation for tire cornering characteristics to be included in shuttle rollout simulators.

Accomplishment
Shuttle astronauts spend many hours in landing rollout simulators training for all the possible emergencies that might arise during this critical phase of an orbiter flight. Fidelity of these landing rollout simulators is highly dependent upon accurate models of orbiter main and nose gear tire friction characteristics. The first test program conducted on the newly updated ALDF was designed to measure the cornering friction characteristics of the orbiter main gear tires and results of this program are presented in the figure. Tests were conducted over a range of yaw or steering angles, ranging up to 10 degrees, vertical loads ranging up to about 150 percent (R=1.5) of tire rated load, and ground speeds up to 220 knots. The figure is a carpet plot which illustrates the influence of yaw angle and load ratio on side force friction coefficient μ_s. The curves in the figure were generated by a bicubic equation which represents a least squares model. On a dry runway surface the tire friction properties were insensitive to speed variations up to 220 knots. This model of the orbiter main gear tire friction characteristics has been installed on shuttle rollout simulators and is being used to train astronauts for shuttle missions.

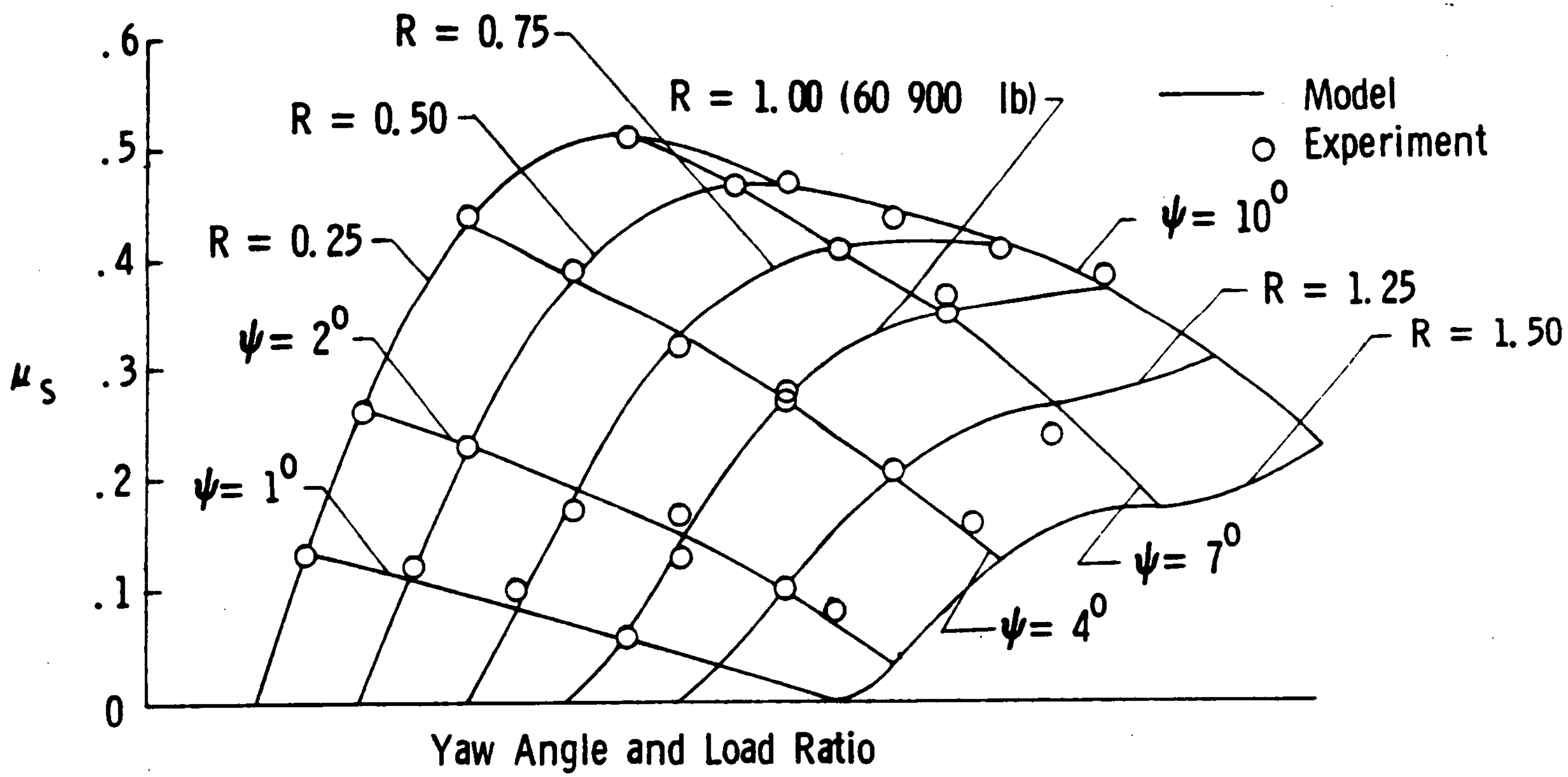
Significance
The friction data for the orbiter main gear tire obtained in this investigation are the first to be acquired at speeds of 220 knots. Previous data were limited to 110 knots. These data form the basis for a national friction data base and will eventually be used to support landing gear research for the National Aerospace Plane.

Future
Additional tests are planned at higher load ratios when a new heavy weight drop test carriage becomes available for ALDF. Additional tests are also planned for the shuttle nose gear tires which were previously tested at speeds up to 110 knots.

SPACE SHUTTLE ORBITER

MAIN GEAR TIRE SIDE FORCE FRICTION COEFFICIENT

KSC RUNWAY



SPINUP WEAR CHARACTERISTICS DEFINED FOR SPACE SHUTTLE MAIN LANDING GEAR TIRE

Sandy M. Stubbs and Robert H. Daugherty
Impact Dynamics Branch
Ext. 2796 JUNE 1986
RTOP 505-63-41 WBS 25-2

Research Objective

The objective of this research is to establish the spinup wear characteristics of the Space Shuttle Orbiter main gear tires and to establish a rational tire wear crosswind limit for the orbiter during landing operations on the Kennedy Space Center (KSC) Shuttle runway.

Approach

Tire spinup tests were conducted on the newly updated Aircraft Landing Dynamics Facility (ALDF) which currently includes a section of simulated KSC runway. Purpose of the tests were to determine the effects of landing speed, vertical sink rate, and runway surface roughness on the wear characteristics of the orbiter main gear tires. Limited tests were also conducted to define the effects of yaw angle and tilt or camber angle on tire wear when the landing is made under crosswind conditions.

Accomplishment

A space shuttle landing subjects the orbiter main gear tires to the most severe spinup wear mechanism faced by any aircraft tire currently flying. Touchdown on the KSC Shuttle Runway at a speed of 220 knots and a sink rate of 3 ft/sec forces each orbiter main gear tire to absorb energy at a rate of approximately 10 000 horsepower. The bar charts in the figure depict the wear experienced by Shuttle tires on a number of runway surfaces. Touchdowns on the KSC runway (simulated at ALDF), which is grooved and highly textured, causes tire spin-up wear that exposes 1 or 2 cord layers in the tire carcass. Efforts to modify the surface by painting, sandblasting and wetting did not significantly reduce this excessive tire wear. Touchdowns on smooth ungrooved runways such as at Edwards AFB do result in reduced tire wear, but these runways are unsafe for Shuttle operations when wet because of the severe hydroplaning potential. Also noted in the figure is the wear depth during touchdown and subsequent rollout in a simulated 20 knot crosswind. This crosswind test wore through 11 out of 16 cord plies of the tire carcass. Consequently the Shuttle is limited to landing operations in a 10 knot crosswind.

Significance

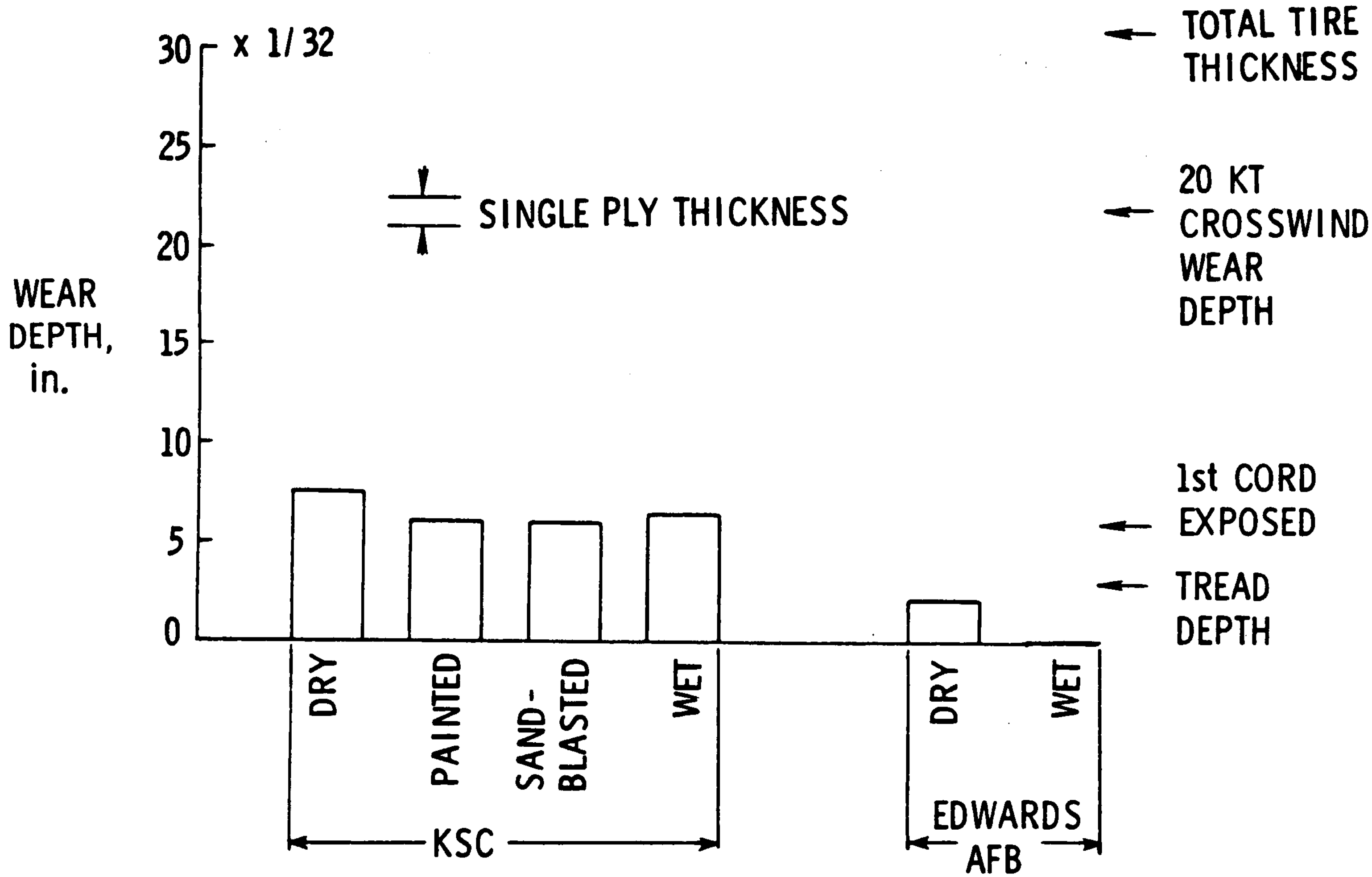
The excessive tire wear observed for the Space Shuttle tires will also be a problem for future aircraft, such as the National Aerospace Plane, required to operate at high landing speeds. These results graphically illustrate the need for further research aimed at reducing tire spinup wear.

Future

Plans are to conduct tests on Shuttle tires which have been equipped with increased thickness tire treads and tire treads with different rubber compounds. Tests are also planned for ALDF to document more fully the tire spinup wear crosswind limits for the KSC Shuttle runway and to study more closely the effect of vertical sink rate on tire spinup wear.

SHUTTLE MAIN GEAR TIRE SPINUP WEAR

220 KNOTS



505-63-4

SPACE SHUTTLE ORBITER MAIN GEAR TIRE SHOULDER WEAR MODEL DEVELOPED

Robert Daugherty and Sandy Stubbs
Impact Dynamics Branch
Ext 2796 July 1986
RTOP 505-63-41
Code RM WBS 25-2

Research Objectives

The objectives of this research is to define the wear characteristics of the Space Shuttle Orbiter main gear tires and to develop a predictive model of these characteristics to be included in shuttle simulators to train the astronauts to handle landing rollout.

Approach

Tire wear tests were conducted on a simulated KSC runway surface at the upgraded Aircraft Landing Dynamics Facility (ALDF) to define the influence of tilt angle on tire shoulder wear. These data were then used to generate a tire wear model for the shuttle main gear tire and the model predictions were compared with tire wear observed following shuttle mission 51-D landing at KSC.

Accomplishment

The excessive tire wear observed on the Orbiter main gear tires following landings at KSC is a concern to the shuttle astronauts and accurate models of tire wear are needed for the training simulators. The line plot in figure 1 shows tilt area plotted as a function of observed shoulder wear. A tire which rolls 10 000 ft at a 2° tilt will be exposed to 20 000 deg-ft of tilt area. The photograph in the figure shows the shoulder wear of the orbiter tire after a 7125 ft roll at 2° tilt. The visible wear on the right shoulder is between 2 and 3 cords exposed. The photographs in figure 2 show the 4 main gear tires afterthe mission 51-D landing on KSC and the plots show the tilt angle histories for each tire. The tilt angles for each tire were a function of strut vertical load, tire side load, and runway crown. The area under each curve should be an indication of the observed shoulder wear. The tilt area and observed wear for each tire in figure 2 were also plotted in figure 1. The excellent agreement between the ALDF tests denoted by the solid line and the wear observed from mission 51-D, denoted by the symbols, indicate that tilt area might be useful as an predictor for tire shoulder wear.

Significance

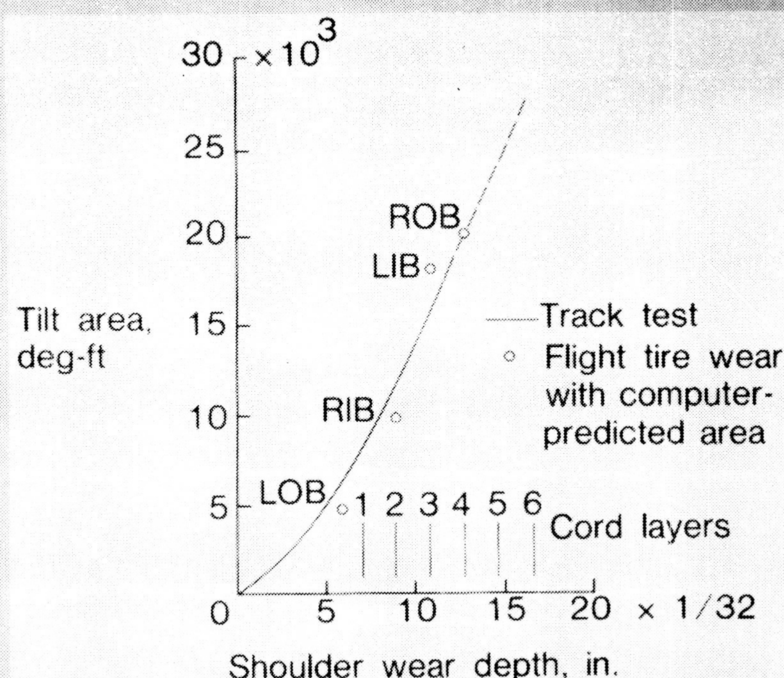
The excessive tire wear observed for the space shuttle tires will also be a problem for future aircraft, such as the National Aerospace Plane, which are required to operate at high takeoff and landing speeds. Accurate models for predicting this wear will be critical to the design of future generations of high performance aircraft tires.

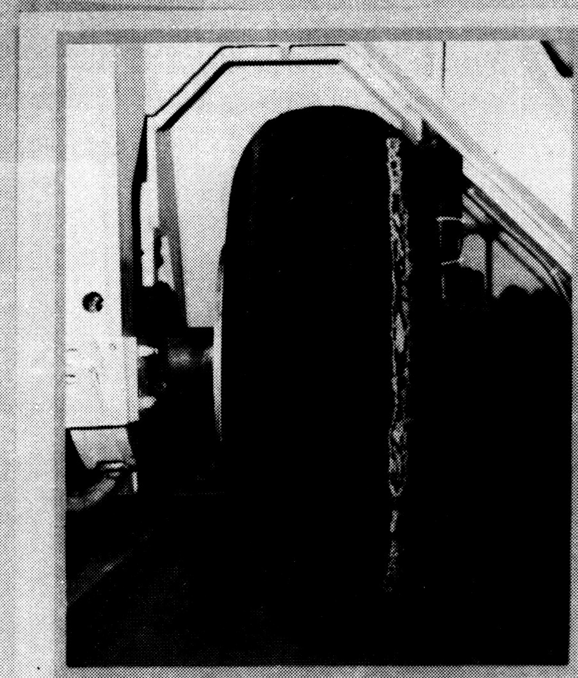
Future

Plans are to conduct additional tests on shuttle tires to establish the effects of crosswind landings on tire wear. These data will be used to define additional tire certification tests to insure safe ground handling operations for the Orbiter fleet.

NASA
L-86-5692

FLIGHT TIRE SHOULDER WEAR PREDICTION





Track test tire
7125 ft 2° tilt

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STRUCTURAL CONCEPTS BRANCH

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TECHNICAL HIGHLIGHT

SPACE STATION SOLAR ARRAY BENDING MOMENTS DUE TO SHUTTLE DOCKING ARE GENERALLY MORE BENIGN FOR GROWTH THAN FOR IOC CONFIGURATION

John T. Dorsey
Structural Concepts Branch
Ext. 2892 December 1985
RTOP 506-43-41
Code RM WBS 55-2

Research Objective

Perform structural dynamic analyses on the space station power tower reference configuration to understand the dynamic behavior and to assess the station performance under various loading conditions.

Approach

Detailed finite element models were generated for both the 75 kW Initial Operating Capability (IOC) space station and a 300 kW growth configuration, with the IOC model having 879 dynamic degrees of freedom (ddof) and the growth model having 2055 ddof. Normal modes were calculated for both stations and transient dynamic responses to an applied shuttle docking load, orbit reboost maneuver, and Mobile Remote Manipulator System (MRMS) translation were calculated. Space station displacements and accelerations were calculated using the mode displacement method and stresses were calculated using the mode acceleration method.

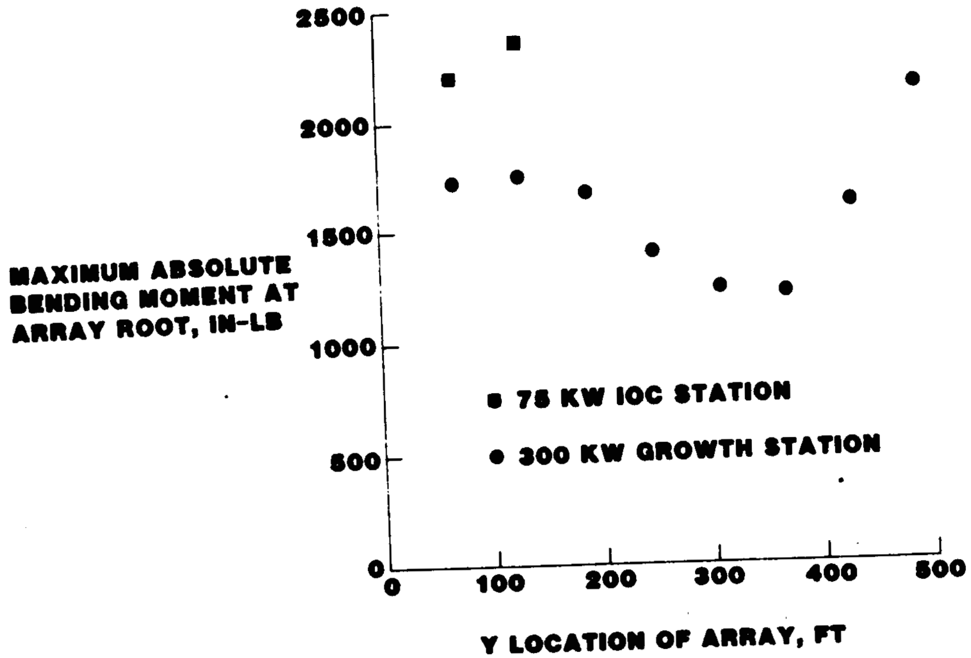
Accomplishment Description

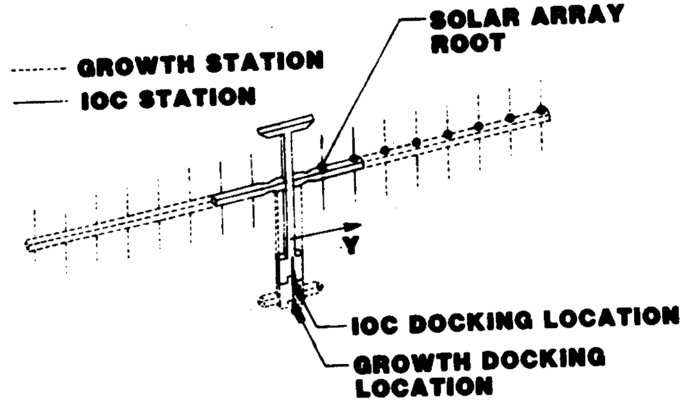
The maximum absolute bending moment at the root of the solar arrays is an example of one of the calculations made in the study and is presented in the chart. The moments were determined for the case of an applied shuttle docking load, where the docking load is a 500 pound rectangular pulse of 1 second duration applied at the base of the station. The results show that the root bending moments due to shuttle docking are generally more benign for the growth station than they are for the IOC station. For both the IOC and the growth configurations, the maximum absolute bending moment occurred at the outboard (greatest Y coordinate) array, with the values being 2400 in-lb and 2100 in-lb respectively. These maximum bending moments are well below the 42,000 in-lb bending strength of the array mast.

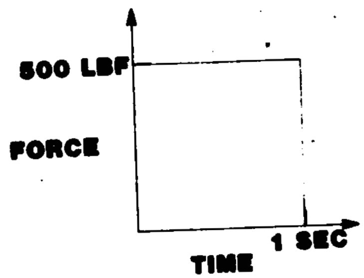
Future Plans

Detailed finite element models will be developed for the new dual keel space station configuration. The performance of this configuration will be assessed using the loading conditions mentioned above.

SPACE STATION SOLAR ARRAY BENDING MOMENTS DUE TO SHUTTLE DOCKING ARE GENERALLY MORE BENIGN FOR GROWTH THAN FOR IOC CONFIGURATION







SHUTTLE DOCKING LOAD

TECHNICAL HIGHLIGHT

SPACE CONSTRUCTION METHODS FOR ERECTABLE STRUCTURES DEMONSTRATED WITH ACCESS SHUTTLE FLIGHT

Walter L. Heard, Jr. and Judith J. Watson
Structural Concepts Branch
Ext. 2608 and 2414 February 1986
RTOP 506-43-41
Code RM WBS 55-1

Research Objective

The objectives of this research program are to: 1) provide on-orbit data for correlation of assembly rates and techniques obtained from neutral buoyancy simulations; 2) gain on-orbit EVA construction experience and; 3) evaluate proposed assembly and maintenance concepts and techniques in support of space station development.

Approach

ACCESS (Assembly Concept for Construction of Erectable Space Structure), an experiment to study manual assembly by astronauts in extravehicular activity (EVA), was flown on the Space Shuttle Atlantis, Mission 61-B. Astronaut mission specialists, Jerry Ross and Sherwood Spring performed the baseline and expanded experiment construction tasks as practiced in preflight neutral buoyancy training at MSFC and JSC. The baseline experiment, performed during the first EVA day, included: 1) unstowing and setting up the assembly fixture; 2) building a 45 foot 10 bay truss beam from 93 4.5 and 6.4 foot struts and 33 nodal joints; 3) disassembling and restowing the truss structure and; 4) restowing the assembly fixture. The expanded experiment, performed during the second EVA day, included: 1) building 9 bays of the truss by the baseline method; 2) assembling the 10th bay by an astronaut in the Manipulator Foot Restraint (MFR) at the end of the RMS robot arm; 3) installing dummy electrical cable; 4) replacing a strut and a node to demonstrate truss repair; 5) manipulating the truss by the astronaut in the MFR including detaching and reattaching the truss to the assembly fixture, and; 6) disassembling and stowing 10 bays of the truss by the baseline method.

Accomplishment Description

The concepts and techniques developed in neutral buoyancy tests were successfully executed on-orbit and proved to be effective methods for space construction. The 45-foot truss structure was built in 26 minutes and 45 seconds showing good correlation with the neutral buoyancy tests. During the two EVAs there were 500 manipulations of untethered hardware with no mishaps, including the manipulation of the assembled 45-foot structure.

Significance

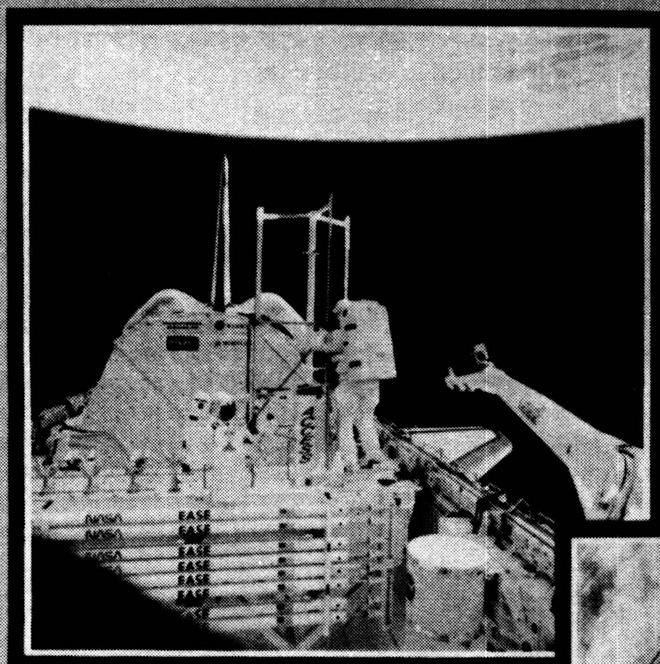
Simplicity and efficiency of space construction by astronauts working in EVA has been demonstrated; neutral buoyancy simulations have been verified, and the success of the experiment has played a role in influencing the decision to baseline space station as a 5-meter erectable truss structure.

Future

Data from video tapes, 16mm movies, and 70mm still photographs are being analyzed. The data, including information from the post-flight debriefing of the astronauts, will be documented.

NASA
L-86-1026

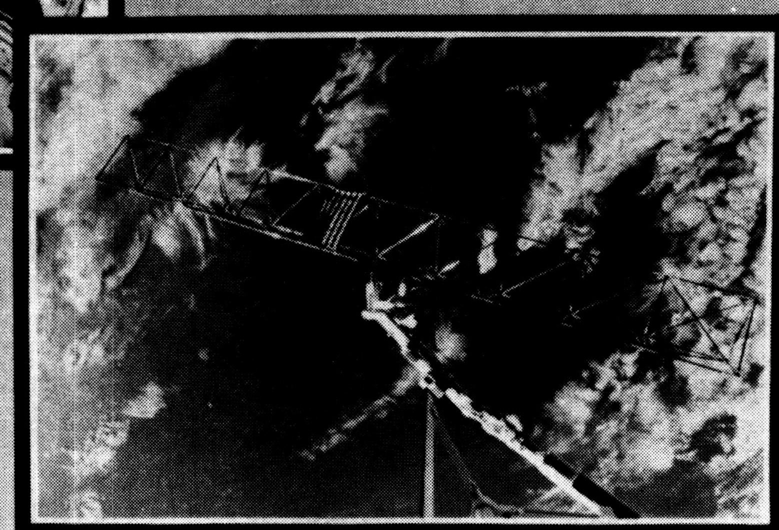
SPACE CONSTRUCTION METHODS FOR ERECTABLE STRUCTURES DEMONSTRATED WITH ACCESS SHUTTLE FLIGHT



- MANUAL ASSEMBLY CONCEPT PROVEN ON-ORBIT
- 45-FOOT TRUSS STRUCTURE BUILT IN 26 MIN. 46 SEC.
- 500 MANIPULATIONS OF UNTETHERED HARDWARE
- GOOD CORRELATION WITH NEUTRAL BUOYANCY SIMULATIONS

RMS FOOT RESTRAINT CONSTRUCTION TASKS DEMONSTRATED

- SEPERATION, MANIPULATION, AND REATTACHMENT OF 190 lbm. 45-FOOT TRUSS
- TRUSS ASSEMBLY/DISASSEMBLY
- CABLE INSTALLATION
- STRUCTURAL REPAIR/MAINTENANCE



TECHNICAL HIGHLIGHT

300 KW DUAL KEEL SPACE STATION STRUCTURES/CONTROLS STUDY AIDED IN SELECTION OF 5M BAY SIZE

John T. Dorsey
Structural Concepts Branch
Ext. 2892 March 1986
RTOP 506-43-41
Code RM WBS 55-2

Research Objective

Assess the effect of truss stiffness (due to different truss bay sizes) on station controllability during attitude control and orbit reboost for a dual keel station.

Approach

Two detailed finite element models were generated for a 300 kw class solar dynamic dual keel space station concept. The first model, where the truss bay size was 5m, had 2238 dynamic degrees of freedom (ddof), and the second model, where the truss bay size was 9 ft, had 3510 ddof. Normal modes were determined for both stations and transient dynamic responses to an off-modulated orbit reboost maneuver were calculated.

Accomplishment Description

The maximum rotation at an outboard solar concentrator during the orbit reboost firing maneuver is an example of one of the calculations made during the study and is presented in the chart. For this maneuver, 75 lbf forces are applied along the flight path (in the +X direction) at the four RCS thruster locations and the rotation at an outboard solar concentrator (point A) is measured. For the solar dynamic system, efficient power generation requires that the total rotation at the concentrator be less than 0.1°. Results are shown for the space station with 5m bays and the station with 9 ft bays which both use a baseline Young's modulus of $30. \times 10^6$ lb/in^2 for the truss members, and for the station with 9 ft bays where the member modulus is reduced by 50%. The results show that both baseline stations would meet the power system pointing requirement, however, because of its proximity to the requirement, any reduction in stiffness will cause the station with 9 ft bays to violate the pointing requirement. In addition, the slope of the curve indicates that concentrator rotation on the baseline station with 9 ft bays is much more sensitive to degradation of truss stiffness than the station with 5m bays.

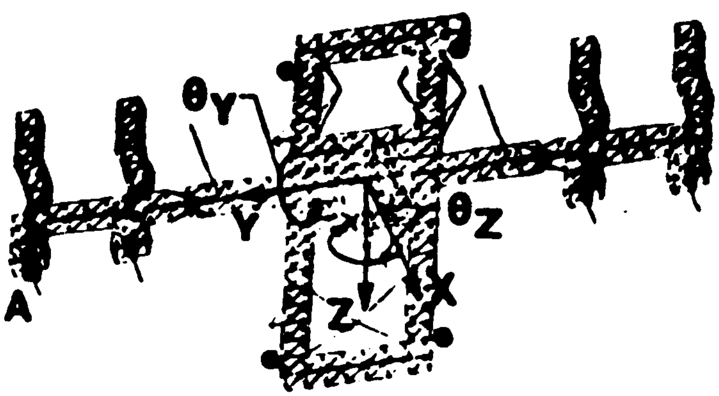
Significance

Results from the transient response studies quantified the relationship between maximum flexible collector rotation and truss stiffness. These results aided in the decision to select the stiffer (5m) bay size for the space station truss structure.

Future Plans

A detailed finite element model of the Initial Operating Capability (IOC) dual keel space station which generates 75 kw of power using photovoltaic arrays will be developed. The performance of the IOC station will be determined and compared to the performance of the growth station.

300 KW DUAL KEEL SPACE STATION STRUCTURES/CONTROLS STUDY AIDED IN SELECTION OF 5M BAY SIZE

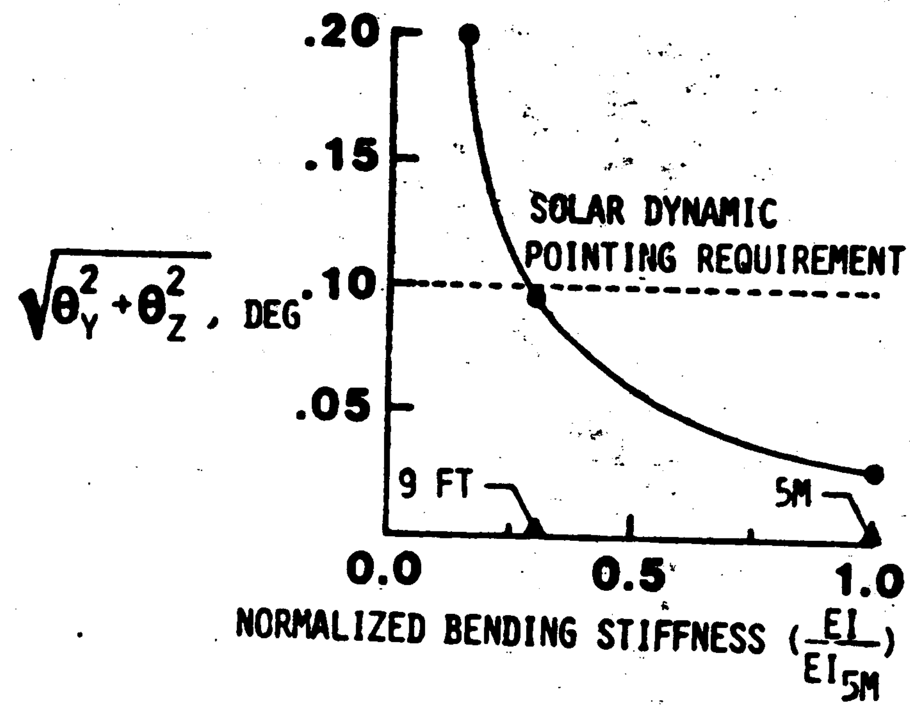


● RCS THRUSTER LOCATIONS

o 5M TRUSS BAYS

o 2238 DYNAMIC DEGREES OF FREEDOM

300 KW SOLAR DYNAMIC SPACE STATION
FINITE ELEMENT MODEL



MAXIMUM OUTBOARD (POINT A) SOLAR DYNAMIC CONCENTRATOR FLEXIBLE·RESPONSE DURING REBOOST VERSUS TRUSS BENDING STIFFNESS

TECHNICAL HIGHLIGHT

METAL CLAD COMPOSITE STRUT FOR SPACE STATION DEVELOPED

Harold G. Bush
Structural Concepts Branch
Ext. 2498 April 1986
RTOP 506-43-41
Code RM WBS 55-2

Research Objective

Develop a structurally efficient, environmentally stable and cost effective truss strut concept for space application.

Approach

Determine the structural characteristics of composite tubing clad internally and externally with metal and methods for incorporating the cladding into the fabrication process. Fabricate tubing for comparison with analytical predictions. (Process development and fabrication being performed under contract.)

Accomplishment Description

A fabrication method for metal clad composite struts was developed which is depicted in the attached figure. Using commercially available metal tubing (e.g.-Al) as a male "mandrel," dry graphite (or any) filament tows are collimated around the outer diameter. The male mandrel and filaments are then pulled into an outer "caul" - which is a larger diameter commercially available tube. After plugging the ends of the annulus between the metal tubes and evacuating, resin is then injected into the cavity under high pressure. With appropriate fittings, hot water or steam is introduced into the inner metal tube to effect resin cure. Finally, the metal is chemically removed (e.g.-chem milling) to the desired thickness, resulting in a high stiffness composite tube which is protected on its inner and outer surface with a finite layer of metal.

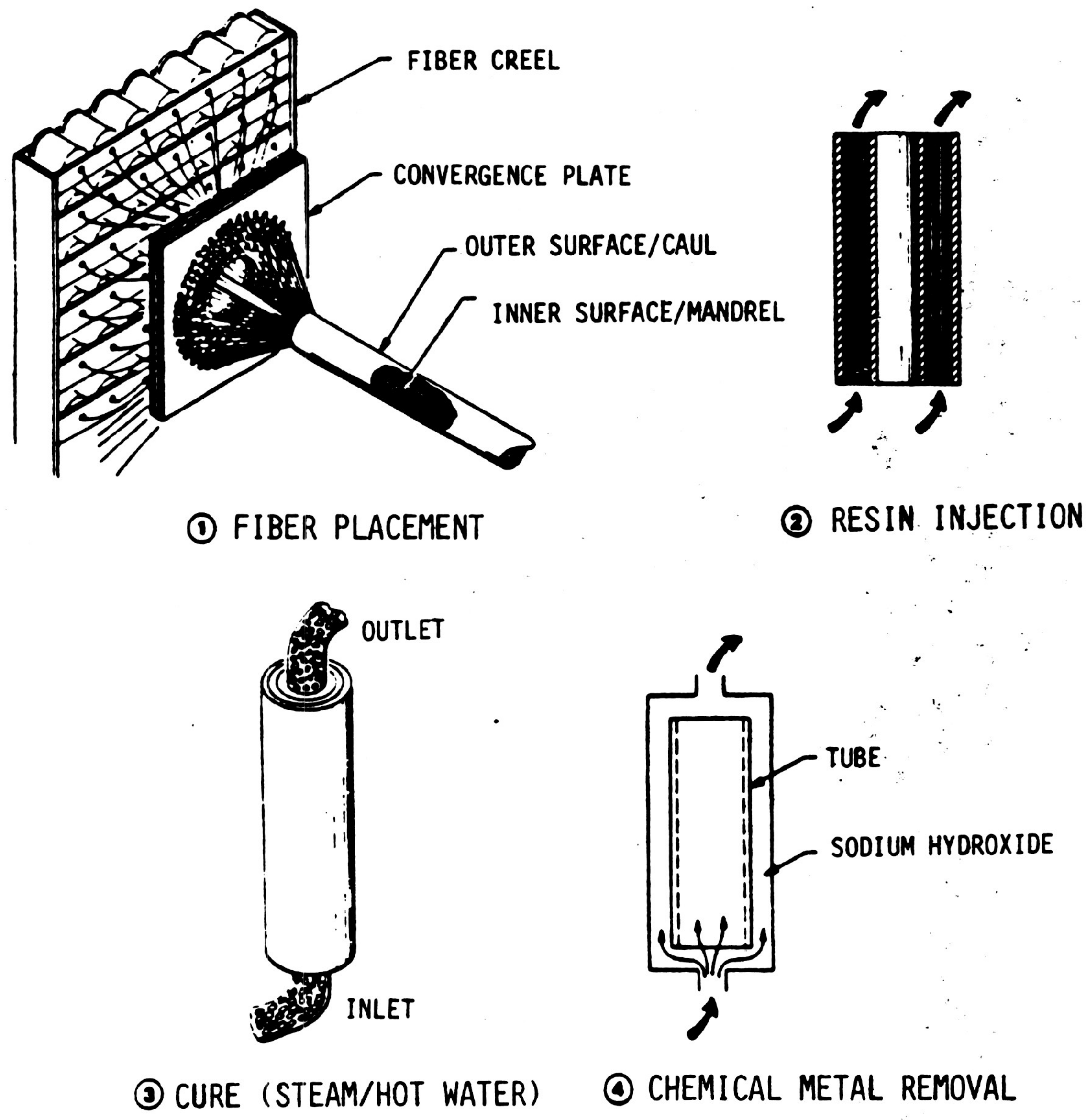
Significance

The tubing concept and fabrication process which has been demonstrated results in struts which have the following advantages: 1) high modulus, 2) post fabrication tunable, low CTE, 3) moisture resistant, 4) atomic oxygen resistant, 5) UV radiation resistant, 6) electrostatic charge resistant, 7) increased circumferential thermal conductivity, 8) increased outgassing control, and 9) significantly reduced microcracking. Additionally, the fabrication process uses the least expensive form of matrix resin and filamentary reinforcement, is non-labor intensive, is independent of facility size (i.e.- ovens or autoclaves), and eliminates conventional tooling. Initial test results have confirmed that design values of strut modulus & CTE (using P75/Epoxy) were attained and that microcracking after thermal cycling was eliminated. A bonded, scarfed structural joint for end fitting attachment has also been successfully tested.

Future

Material and structural characterization tests will be performed to provide complete understanding of strut performance. Impact testing (which has been started) will be completed and/or expanded as required.

METAL CLAD COMPOSITE TUBE FABRICATION PROCESS DEVELOPED



STRUCTURAL DYNAMICS BRANCH

TECHNICAL HIGHLIGHT

SLEWING CONTROL SUCCESSFULLY DEMONSTRATED FOR FLEXIBLE SOLAR PANEL

Jer-Nan Juang and Lucas G. Horta
Structural Dynamics Branch
Ext. 2881 November 1985
RTOP 506-43-51
Code RM WBS 42-1

Research Objective

The objective of the present experiment is to demonstrate slewing of a flexible structure in a single axis while simultaneously suppressing vibrational motion at the completion of the maneuver. This experiment is designed to verify theoretical analyses concerning the application of modern control methods to the control of flexible structures.

Approach

A 13-foot-long flexible solar panel model having a cross section of 2.1 ft x .13 in. is used for experimental validation. The test model is cantilevered in a vertical plane and rotated in the horizontal plane by an electric gearmotor. Instrumentation consists of three full-bridge strain gages to measure bending moments and two angular potentiometers to measure the angle of rotation at the root. The strain gages are located at the root, at twenty-two percent of the panel length, and at the mid-span. Signals from all four sensors are amplified and then monitored by an analog data acquisition system. An analog computer closes the control loop, generating a voltage signal for the gearmotor based on a linear optimal control algorithm with terminal constraints in finite time.

Accomplishment Description

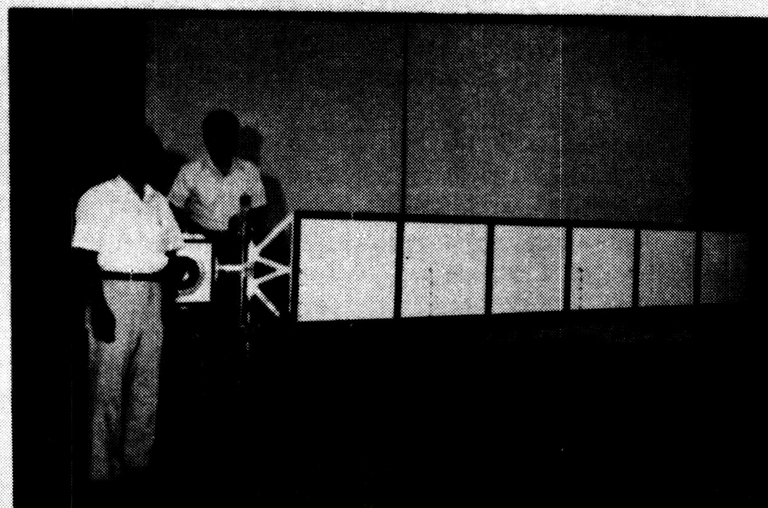
A slewing control approach for flexible structures has been experimentally demonstrated. The controller successfully performed large-angle maneuvers and damped out flexible modes by the end of the maneuver. The Figure shows an example of results for a 30-degree slew in 3.5 seconds. When no control is used, residual motion is significant, whereas the controller produces the same maneuver with virtually no residual motion. Satisfactory agreement was achieved between experimental measurements and theoretical predictions. Nonlinear effects due to large bending deflections during the maneuver did not cause significant changes in performance of the control laws, which were designed using linear control theory. To minimize the excitation of flexible modes, a low-pass filter was used to shape the control torque input. This shaping proved beneficial for fast slewing maneuvers.

Future plans

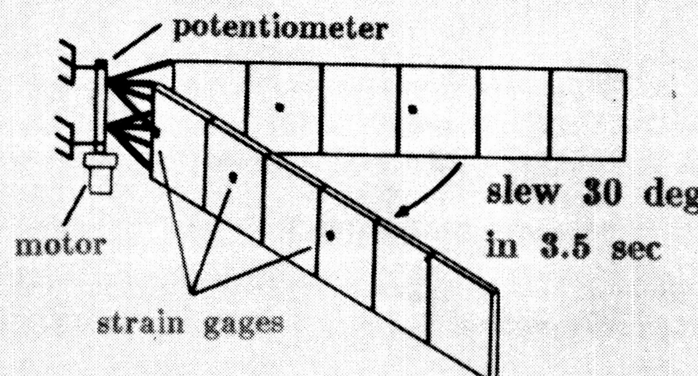
The effect of air drag on slewing control experiments will be studied. The hardware will be modified to study the slewing control of multiple solar panels attached to a rigid body.

NASA
L-85-11,996

TEST SET-UP

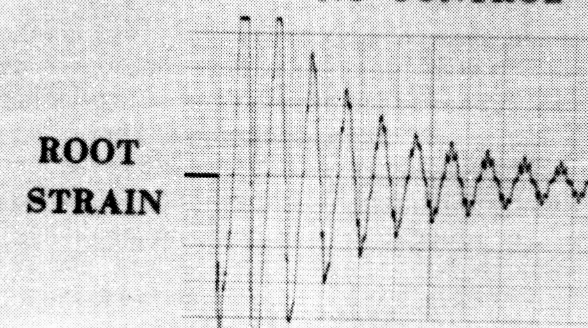


13–foot long aluminum/honeycomb panel

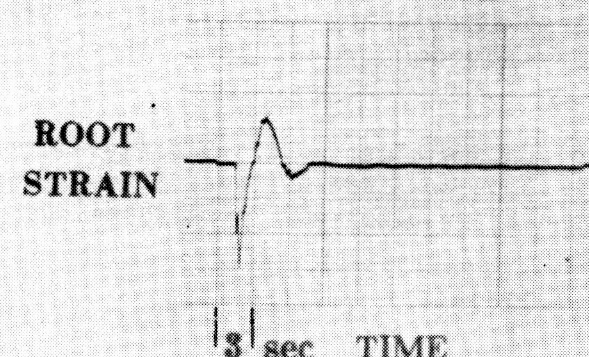


EXPERIMENT

NO CONTROL



CONTROL



DYNAMIC ANALYSIS SUCCESSFULLY ACCOUNTS FOR TEST SUSPENSION SYSTEM

W. Keith Belvin and Harold H. Edighoffer
Structural Dynamics Branch Edighoffer, Inc.
Extension 2446
June 1986
RTOP 506-43-51
Code RM WBS 42-1

RESEARCH OBJECTIVES: To develop dynamic analysis and experiment methods for space station models and to assess the effects of cable suspension systems and ambient air on model vibrations.

APPROACH: A generic dynamics model was constructed to simulate the multi-body, low frequency nature of large space structures such as the space station. The generic model was tested and analyzed to develop ground vibration test methods and to verify analysis techniques which include the effects of cable suspension systems.

ACCOMPLISHMENT DESCRIPTION: Large space systems require accurate dynamic analyses to insure that structural vibrations do not adversely impact performance. Verification and refinement of dynamic models is typically performed using ground vibration test data. The low stiffness and vibration frequencies of large space structures, however, can require suspension systems for tests which couple with structural vibration modes. Each substructure of the generic model shown on the attached chart was tested and the data was used to refine the substructure analysis models. The substructure analysis models were assembled to analyze the entire structure in two ways, as cable suspended and free-free. Measured and computed frequencies for the cable-suspended case, as shown on the attached chart, indicate that some modes are significantly altered by the cable suspension. Applying prestressed vibration analysis to include the stiffness effects of the cables resulted in good agreement between test and analysis. Free-free analysis predicted modes 4 and 5 adequately and mode 1 is clearly rigid body motion although its measured frequency is not accurately predicted without including suspension pendulum effects. Modes 2 and 3 were significantly influenced by the cable suspension. As shown in the lower right portion of the chart, a double pendulum suspension mode couples with the first bending mode of the model. The level of coupling is strongly affected by the distance from the cable attachment to the model center of gravity requiring accurate modeling of the cable-to-model attachment to correlate with ground vibration test data. Other results obtained in this study include development of a noncontacting electromagnet shaker and an assessment of ambient air effects by comparing tests in vacuum and atmospheric pressure. Ambient air increased modal damping by 29 percent and decreased model frequencies by 3.1 percent on average.

SIGNIFICANCE: Although free-free boundary conditions cannot be duplicated in ground vibration tests, the analysis and test methods developed in this study enable cable suspension effects to be properly included in the analytical models. Thus, ground vibration test data can be used to verify analysis of large, low frequency space structures.

FUTURE PLANS: Active vibration suppression of solar array vibrations is being performed. Additional modal synthesis analysis may be performed.

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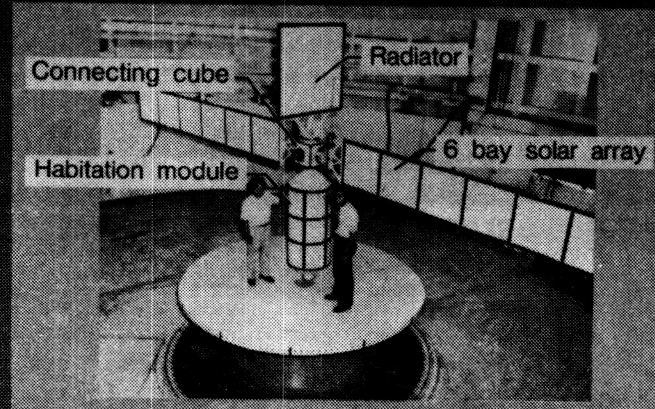
DYNAMIC ANALYSIS
SUCCESSFULLY ACCOUNTS FOR TEST SUSPENSION SYSTEM

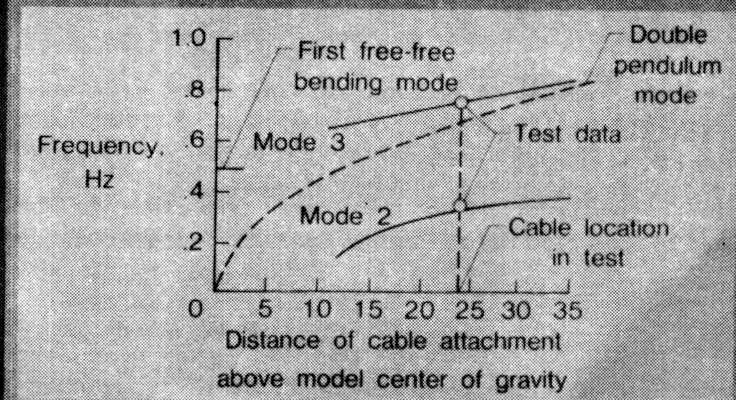
Generic space station model



Model frequencies

Mode number	Test	Analysis: Cable suspended	Analysis: Free-free
1	0.125	0.129	0.0
2	0.353	0.324	0.0
3	0.750	0.757	0.492
4	1.24	1.29	1.31
5	2.74	2.84	2.87

Cable suspension coupling



LINEARIZED ANALYSIS PREDICTS VIBRATION FREQUENCY OF TRUSS WITH NONLINEAR JOINTS

W. Keith Belvin
Structural Dynamics Branch
Extension 2446 July 1986
RTOP 506-43-51
Code RM WBS 42-1

RESEARCH OBJECTIVE: To develop analytical models for typical truss joints based on empirical data and to incorporate these models into finite element analyses for simulation of truss structure dynamic responses.

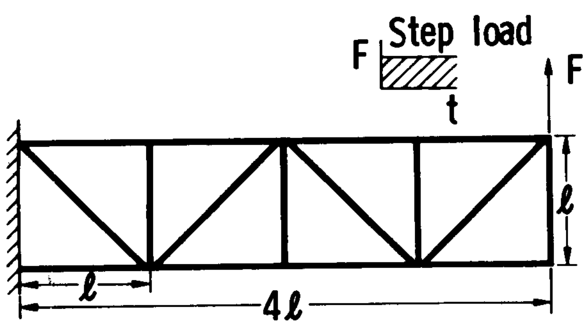
APPROACH: Measured load-deflection data from structural joints are approximated by a set of nonlinear mechanisms with adjustable stiffness and damping coefficients. This empirically-based joint model is then incorporated into a global finite element analysis which permits nonlinear dynamic response simulation using an explicit integration scheme.

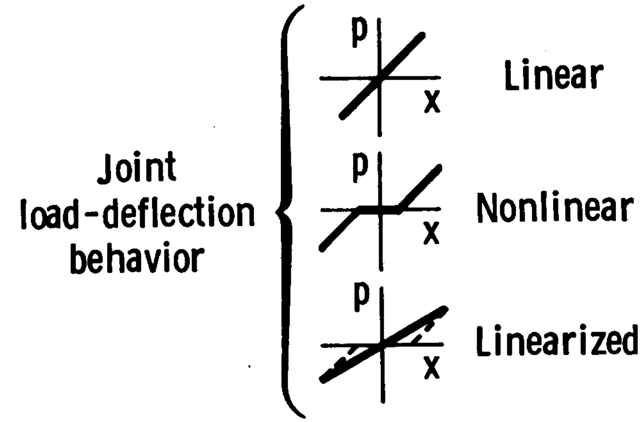
ACCOMPLISHMENT DESCRIPTION: Truss structures are proposed for use in space because of their high stiffness to mass ratio. The stiffness and damping of joints used to connect truss members can, however, have significant effects on global truss vibrations. Thus, structural analysis methods which include effects of joints are desired to study the influence of joints on truss performance. An optimization algorithm for computing stiffness and damping coefficients for joints using experimental load-deflection data has been developed. The algorithm uses a nonlinear least-squares error analysis to minimize the error between predicted and measured load-deflection curves. Linear and nonlinear stiffness and damping coefficients computed by the algorithm represent an empirical model which may be used in global truss analysis. The attached chart shows a two-dimensional 4-bay truss which has been analyzed with a finite element program to predict nonlinear truss vibrations. Each truss member has two joints, one on each end of the beam. Results are shown for linear, nonlinear and a linearized joint load-deflection behavior as indicated in the upper-right portion of the chart. Linear analysis does not predict the frequency or amplitude of vibration when a deadband or gap is present in the joints. As shown in the lower left graph, nonlinear analysis predicts a significantly larger vibration amplitude and lower frequency than does the linear analysis. The figure on the lower right shows that for constant amplitude vibrations, a linearized approximation of the joint behavior predicts the frequency of vibration but not the vibration amplitude of the nonlinear results. A method for empirical joint model development and subsequent inclusion into global analysis has been developed in this study. The method of joint modeling allows linear and nonlinear joint effects on global truss vibrations to be simulated.

SIGNIFICANCE: The space station and other large space structures require accurate prediction of truss structure vibrations. The analysis procedure developed in this study allows the analyst to predict the effect of joint stiffness and damping on global vibrations. Linearized analysis of nonlinear truss behavior will permit steady state vibrations to be simulated with significantly less computational effort than full nonlinear analysis.

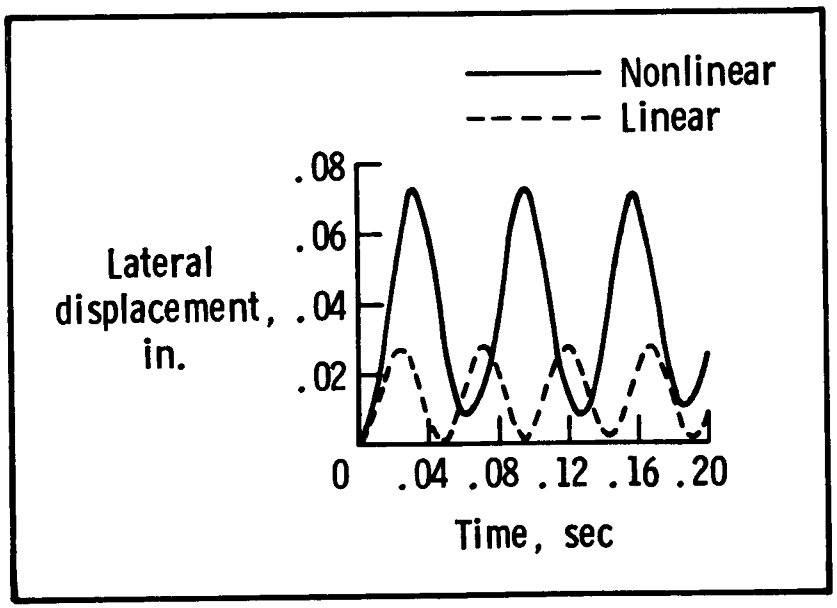
FUTURE PLANS: Susbstructure techniques to reduce the computational requirements of the nonlinear analysis are being developed. In addition, development of linearization procedures to obtain approximate linear models of nonlinear joint behavior will be studied.

LINEARIZED ANALYSIS PREDICTS VIBRATION FREQUENCY OF TRUSS WITH NONLINEAR JOINTS

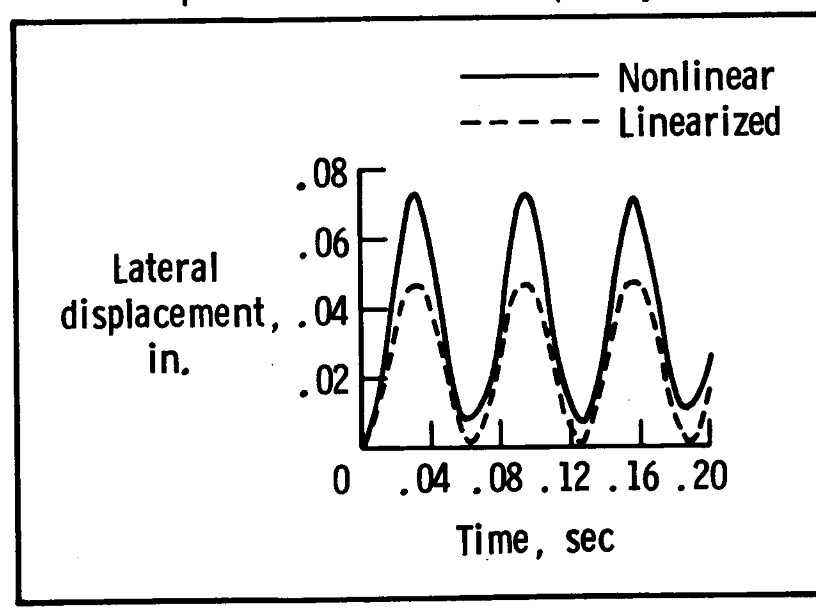




Linear analysis insufficient



Linearized analysis predicts nonlinear frequency



MSC ARM MANEUVER ON SPACE STATION

Jerrold M. Housner

Structural Dynamics Branch
Ext. 3055 September 1986
RTOP 482-53-53
Code RM WBS 42-1

RESEARCH OBJECTIVE: Develop an analytical capability for establishing response environments on space station due to articulating subsystems.

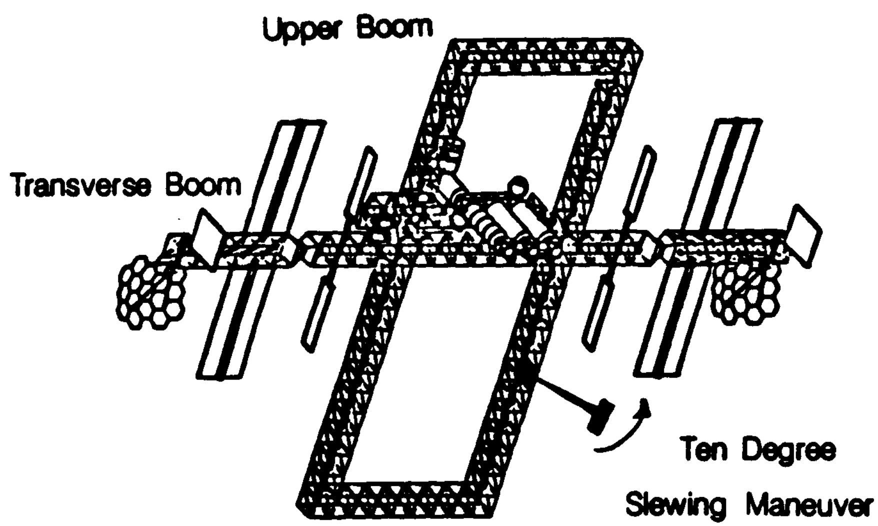
APPROACH: The LATDYN computer program (Large Angle Transient DYNamics) has been developed for analytical simulation of flexible structures with multiple components undergoing large relative angular motions. Presently the program is operational in 2-dimensional geometry. The 2-D version is used to predict response accelerations at selected station locations resulting from the controlled articulation of a 32,000 pound payload at the tip of a remote manipulator system (RMS) located mid-way along the lower half of one of the keels.

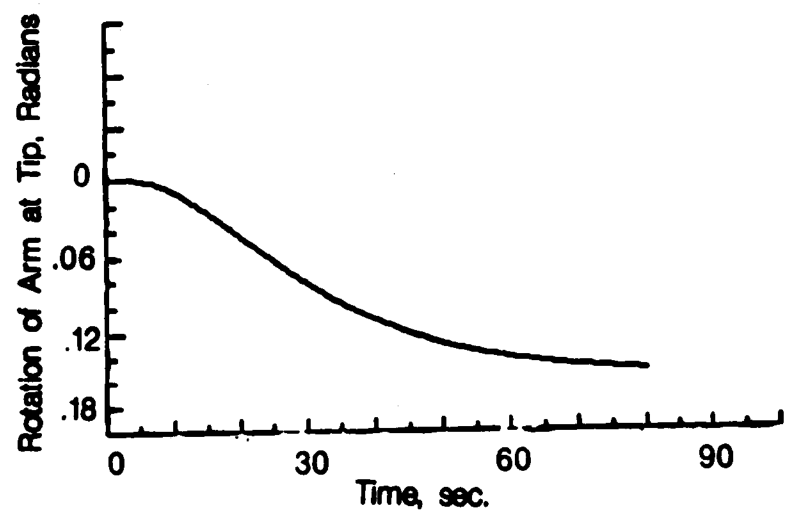
ACCOMPLISHMENT DESCRIPTION: The space station is a center for routine on-orbit operations, some of which will involve the articulation or slewing of payloads. In the accompanying chart, the RMS is given a command to slew a 32,000 payload through an angle of ten degrees in 80 seconds. This is a very slow maneuver, corresponding to an angular rate less than twice the orbital rate. A motor at the root of the RMS produces the necessary torque. Using angular-rate feedback control, the actuator is also used to supress the vibrations of the RMS during and after the maneuver. As shown in the accompanying figure, the simulation analysis predicts that the controlled angular motion is accomplished smoothly, with little or no vibration of the RMS. However, the maneuver will naturally produce an overall angular response of the station and possible vibratory station response. It is assumed in accordance with the present space station baseline, that there is no station active vibration suppression system. Also, the RMS control system is not designed to suppress vibrations of the station. Thus, certain station locations experience vibrational transients due to such maneuvers. For example, the vibratory component of the response on the station's upper boom, where star gazing equipment may be located, is a significant part of the overall response at this location. On the other hand, the response of the transverse boom contains little vibration.

SIGNIFICANCE: The LATDYN computer program, even in its 2-D form, is a useful tool for simulating space station operations where large angular motions are involved. This application of the program indicates that even controlled slow operations on the space station can result in considerable vibratory response at certain station locations.

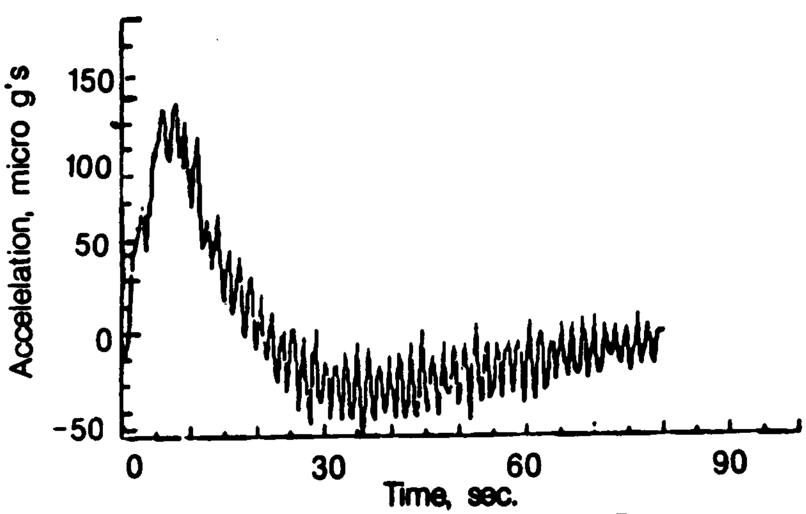
FUTURE PLANS: Development of LATDYN to allow for three dimensional capability is in progress.

MSC ARM MANEUVER ON SPACE STATION

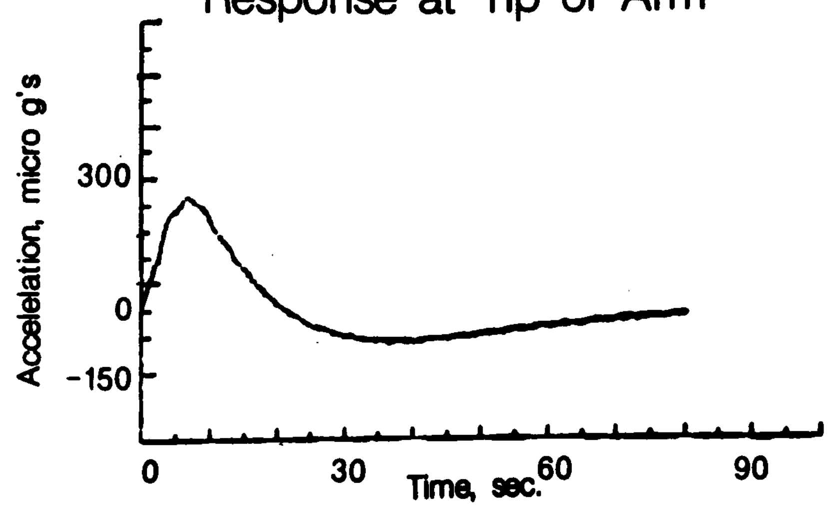




Response at Tip of Arm



Response on Upper Boom



Response at Tip of Transverse Boom

CLOSED-LOOP SIMULATION VERIFIES AND IMPROVES COFS-I CONCEPT

Lucas G. Horta, Garnett C. Horner
and James P. Bailey

Structural Dynamics Branch
Ext. 2738 September 1986
RTOP 506-43-51
Code RM WBS 42-1

RESEARCH OBJECTIVE: Simulate in-flight behavior of the orbiter/COFS-I spacecraft to verify the viability of design and test approaches. Study effects of design limits on achieving measurable excitation and control levels using proof-mass actuators.

APPROACH: The study uses a truncated modal model of the COFS-I truss-beam with actuators attached at bays 12, 30, 44, and the tip (see figure). Each actuator is modeled analytically by three parameters; control force, $f(u,v,t)$, viscous damping, c, and stiffness, κ. A test sequence is divided into three stages; excitation, dwell (free vibration), and damping (control). During excitation, the actuators impart sinusoidal forces to the truss-beam. When dwelling, no force is commanded. During damping, the actuator opposes beam motion with a commanded force proportional to the local beam velocity.

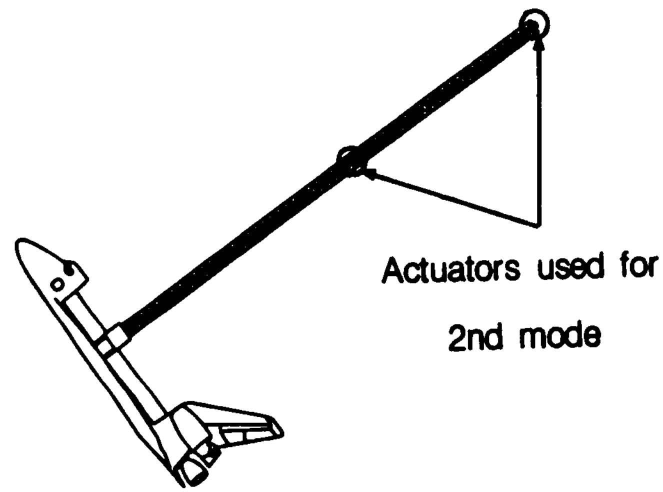
ACCOMPLISHMENT: The attached figure shows an example of simulating a test sequence for the second structural mode. Actuators at the tip and bay 30 are used (see arrows). The plot on the lower left figure shows a complete test sequence of the proposed flight experiment. The test includes excitation of the second bending mode to a 1 cm tip deflection, dwelling, and damping (5% of critical). The study reveals the need for and develops an approach for using multiple actuators during excitation and damping of the higher modes. Initial contractor designs used a free-floating actuator reaction mass with a crude centering control. LaRC simulations indicate that an actuator position-feedback control loop (effectively a centering spring) is necessary. Results for the case of no position loop ($k=0$) during excitation indicate that although the test can be conducted theoretically, the actuator mass displacement (stroke) increases rapidly, as shown on the low right of the figure, and hits physical limits in a few cycles. As a result of this study, an actuator position control loop is being added to the COFS I hardware.

SIGNIFICANCE: The necessity of including complete actuator equations of motion in the design process for vibration excitation and control is demonstrated and a potentially expensive shortcoming in the COFS-I design was found early in the program.

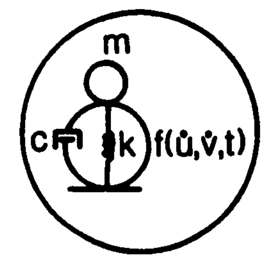
FUTURE PLANS: Studies of broad-band capabilities and trade-off studies to determine requirements for power, force, and stroke levels.

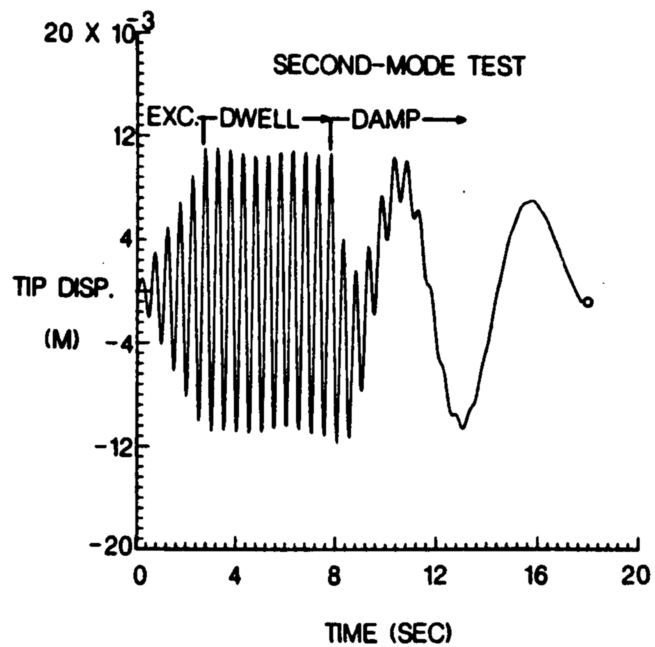
CLOSED-LOOP SIMULATION VERIFIES AND IMPROVES COFS-I CONCEPT

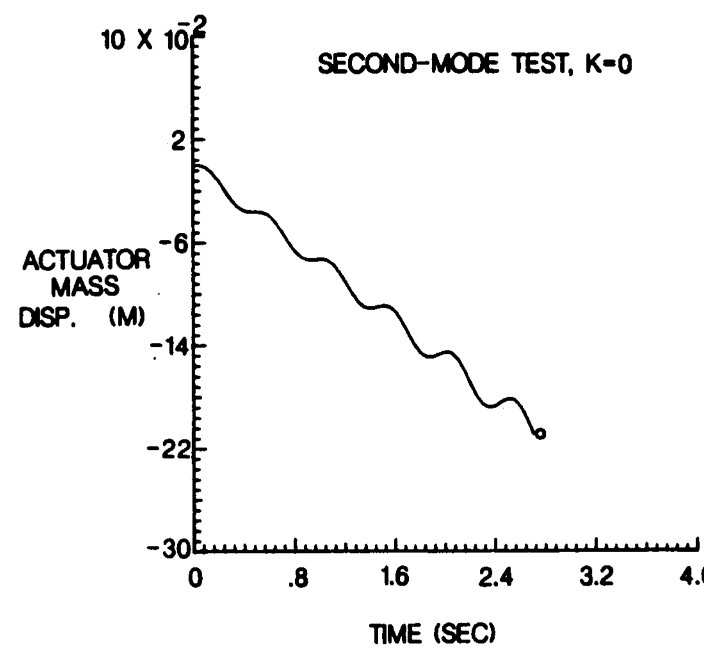
COFS-I



ACTUATOR MODEL







STRUCTURAL MECHANICS BRANCH

TECHNICAL HIGHLIGHT

INTRALAMINAR SHEAR FAILURE MODEL EXPLAINS DAMAGE TOLERANCE BENEFITS OF USING TOUGH RESINS AND ADHESIVE INTERLAYERS

Jerry G. Williams
Structural Mechanics Branch
Ext. 4052 October 1985
RTOP 534-06-23 and 505-63-11
Code RM WBS 56-1

Research Objective

To develop a physical model of the initiation and propagation of damage in composite laminates due to local bending and impact and to understand the improved damage tolerance derived from tough resins and adhesive interleaving.

Approach

A five-point beam test method was developed to study the local deformation response of a composite laminate subjected to local bending or low-speed impact. Tests were conducted on selected composite material systems and load-deformation responses and cross-sectional failure modes were compared.

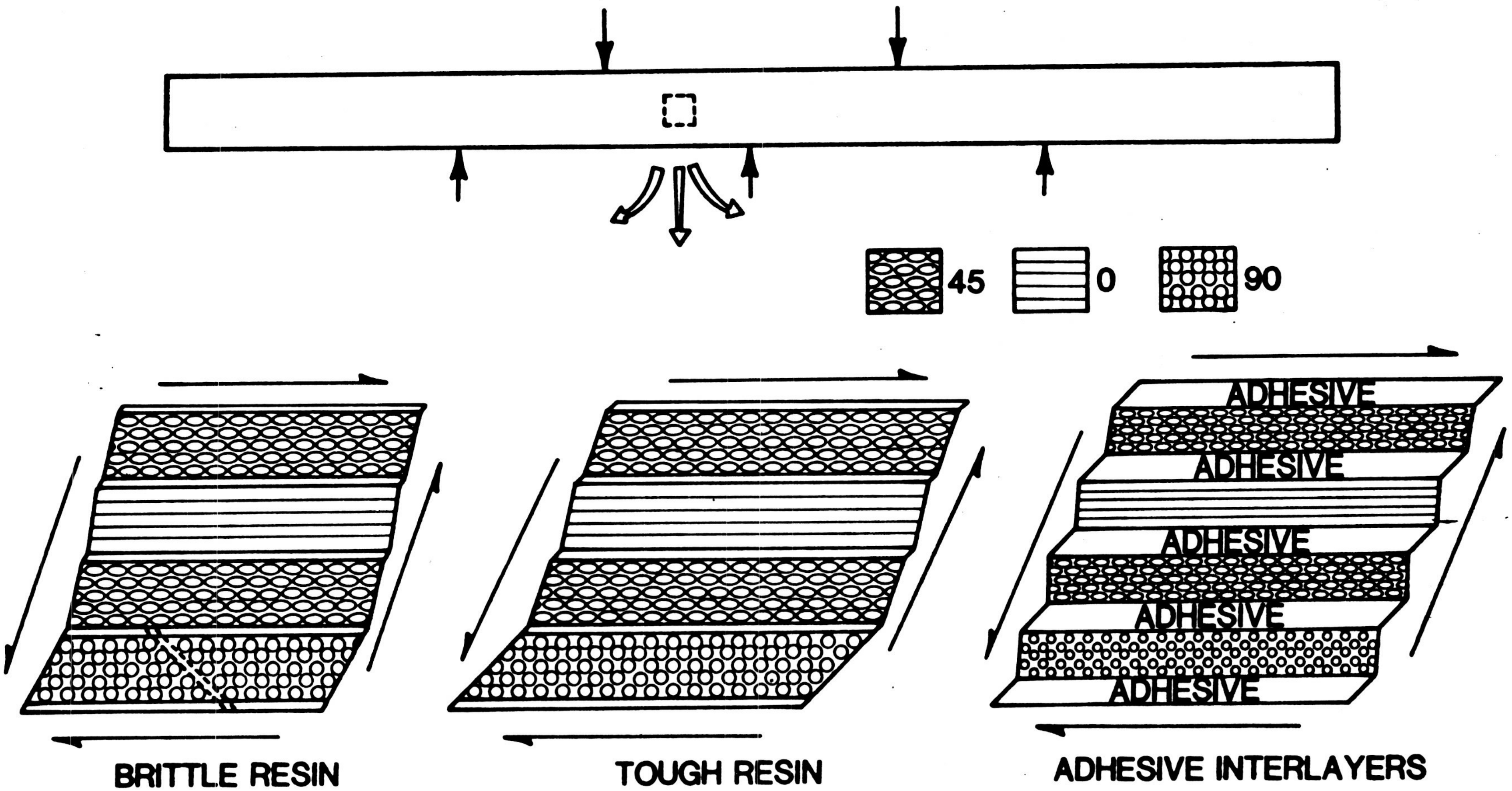
Accomplishment Description

Nearly pure transverse shear exists in the central region (dashed square in the upper figure) of a beam loaded in five-point bending. The shear deformations in this central region for [±45/0/90] beams made of a brittle resin, a toughened resin, and a brittle resin with adhesive interlayers are shown in the lower figures. The transverse shear stiffness of each layer affects the shear deformation angles shown in the lower figures. The 0° plies have the highest stiffness and the smallest shear angle; the 90° plies have the lowest stiffness and the largest shear angle, and the 45° plies have intermediate values. Failure is initiated by matrix cracking in the angle plies (90° and 45° plies) of the brittle resin beams as indicated by the diagonal crack in the 90° ply in the lower left figure. The crack in the 90° ply is oriented at approximately 45° to the beam axis and coincides with the weak principal-tension-stress direction in the shear-loaded matrix. Microscopic examination reveals that this intralaminar shear failure occurs before any other failure mode and is sometimes followed by delamination propagation between plies. Beams made of toughened resins can withstand greater shear deformations than those made of brittle resins as shown in the lower center figure. As a result, these beams have better resistance to failure associated with local bending or impact. Intralaminar shear failures were observed in the angle plies of tough-resin beams, but the damage did not propagate by delamination between plies. Beams made of brittle resins with low-shear-modulus adhesive interlayers between plies have large shear deformations in the adhesive interlayers as shown in the lower right figure. The shearing deformation of the adhesive interlayers tends to isolate the brittle-resin plies from severe shearing deformation and, as a result, delays the intralaminar shear failure mode and improves the beam bending strength. Intralaminar shear failure was observed for very large deformations, but the adhesive interleaving suppressed delamination between plies.

Future Plans

Additional tests are being conducted to study the effects of local discontinuities such as a cut ply on damage initiation and propagation. Analytical models will be developed to predict the experimental observations.

INTRALAMINAR SHEAR FAILURE MODEL EXPLAINS DAMAGE TOLERANCE BENEFITS OF USING TOUGH RESINS AND ADHESIVE INTERLAYERS



TECHNICAL HIGHLIGHT

SKIN-STIFFENER-INTERFACE STRESS DISTRIBUTIONS DETERMINED FOR GRAPHITE-EPOXY PANELS WITH POSTBUCKLING STRENGTH

Norman F. Knight, Jr. and James H. Starnes, Jr.
Structural Mechanics Branch, SDD
Ext. 4892/2552 November 1985
RTOP 505-63-31
Code RM WBS 56-1

Research Objective

To develop an analytical model of the interface stress distributions in the adhesive layer between the panel skin and the stiffener attachment flange for compression loaded graphite-epoxy stiffened panels.

Approach

An analytical model of the skin-stiffener-interface stress distributions for stiffened graphite-epoxy panels was developed and included in the POSTOP computer code (Postbuckled Open-STiffener Optimum Panels) by the Lockheed-Georgia Company under NASA Contract NAS1-15949.

Accomplishment Description

Using the POSTOP computer code, the stress distributions in the adhesive interface layer are determined for three values of skin loading above the buckling load. Stress distributions across the width of a stiffener attachment flange b_f are shown in the chart as a function of the distance y measured from the stiffener web midplane. The shaded regions in the chart represent nominal design allowables for the interface adhesive material. The nominal design allowable values for the normal stress are 8 ksi in tension and 30 ksi in compression and the value for the transverse shear stresses is 9 ksi. Since POSTOP does not currently have a free-edge stress singularity analysis or a progressive failure analysis capability to relieve any severe local stress concentrations, unusually large stresses for the interface material system may result from the analysis. The normal stress σ_z distribution shown in the upper left figure and the transverse shear stress τ_{yz} distribution shown in the upper right figure indicate that significant stress gradients can exist in the skin-stiffener-interface region after buckling has occurred. The maximum values for the σ_z and τ_{yz} stresses occur near the stiffener web and exceed the nominal design allowables for the interface material for the values of skin loadings considered. As the longitudinal inplane loading in the skin is increased, the stresses that exceed the nominal design allowables extend toward the free edge of the stiffener attachment flange. The transverse shear stress τ_{xz} distribution shown in the middle figure indicates that a severe free-edge stress gradient exists at the edge of the attachment flange. These severe stress gradients are believed to be the cause of the skin-stiffener-separation failure mode as shown in the bottom figure that limits the postbuckling performance of stiffened graphite-epoxy panels.

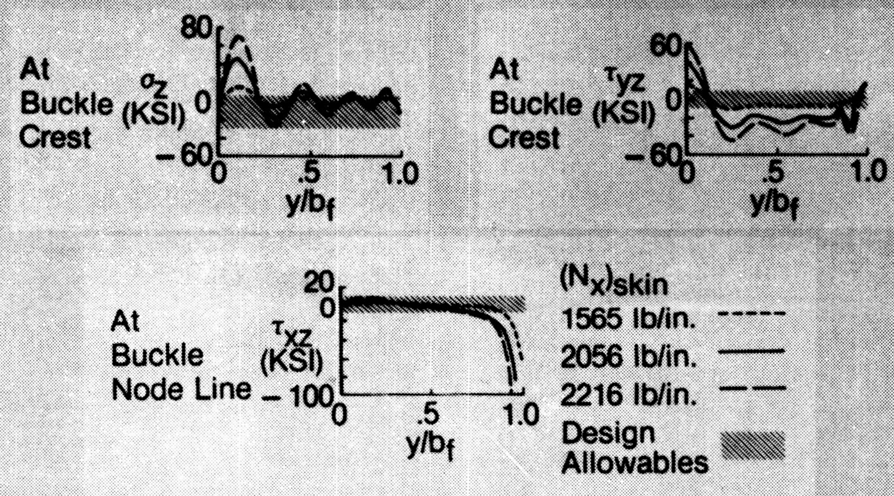
Future Plans

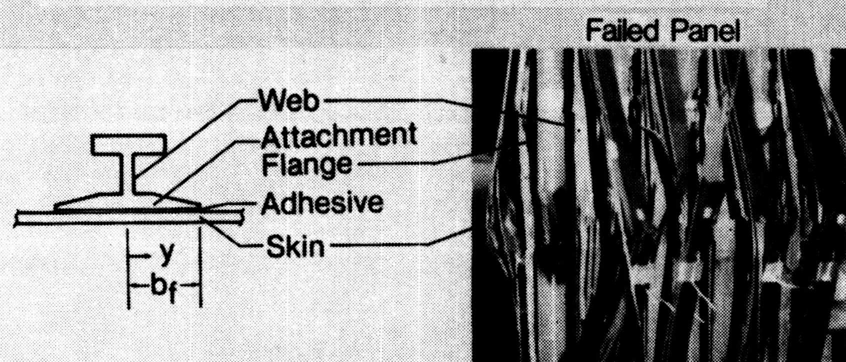
An analytical effort to model the free-edge singularity and to develop a failure criterion is currently being investigated under contract with the Lockheed-Georgia Company (NAS1-15945).

NASA
L-85-10,991

SKIN-STIFFENER-INTERFACE STRESS DISTRIBUTIONS DETERMINED FOR GRAPHITE-EPOXY PANELS WITH POSTBUCKLING STRENGTH

16-Ply Skin, R = 85 in. and 4.0-inch Stiffener Spacing





At Failure
(N_x) skin = 2629 lb/in.

NASA L-6992-12 N. KNIGHT 4/15-17/85

ADHESIVE INTERLEAVING SIGNIFICANTLY IMPROVES COMPRESSION-AFTER-IMPACT STRENGTH

Jerry G. Williams and Dawn C. Jegley
Structural Mechanics Branch
Ext. 4052 January 1986
RTOP 534-06-23 and 505-33-33
Code RM WBS 56-1

Research Objective

To evaluate the compression-after-impact performance of advanced material systems for heavily-loaded aircraft structures and to understand the failure mechanics of composite structures made from these systems.

Approach

A NASA developed compression-after-impact damage-tolerance test was used to evaluate the residual strength of several material systems including a thermoplastic material (PEEK) and a new concept for a damage-tolerant material in which an adhesive layer is sandwiched between each layer of the laminate.

Accomplishment Description

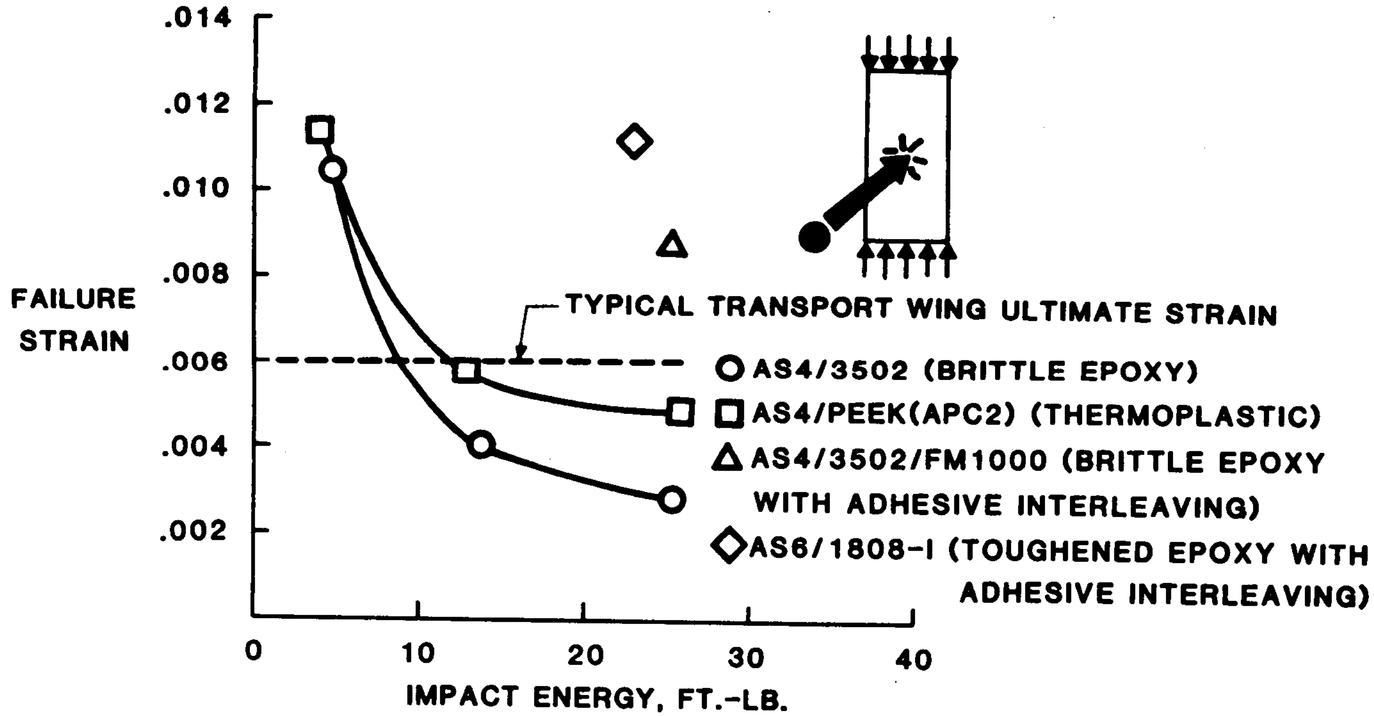
The failure strains for 1/4-in.-thick quasi-isotropic plates made of several material systems are plotted on the attached figure as a function of the impact energy corresponding to impact damage by a 1/2-in.-diameter aluminum sphere. The failure strain for the AS4/3502 material of approximately 0.003 for an impact energy of 25 ft-lbs. is representative of the compression-after-impact strength of brittle epoxy systems. The AS4/PEEK (APC2) material has a higher compression failure strain (approximately 0.005) for this condition. Even greater improvement in compression-after-impact failure strain, however, was recorded for the two materials with adhesive interleaving. The AS4/3502/FM1000 specimen has a 0.003-in.-thick layer of FM1000 adhesive between each layer of AS4/3502 tape and a failure strain of 0.009. The AS6/1808-I interleaved specimen has a failure strain of 0.011 following impact by 22 ft-lb of energy which corresponds to a failure stress of 65 ksi. The adhesive thickness for AS6/1808-I is 0.0005 in. which adds approximately 10 percent weight to the laminate compared to a non-interleaved material, but increases the compression-after-impact strength by approximately 250 percent.

The dramatic improvement in impact damage tolerance provided by interleaving is believed to be related to the adhesive's nonlinear stress-strain response in both shear and tension which enables the laminate to experience large transverse deformations during impact without significant delamination or intralaminar failure. Also, local damage can be detected at energy levels well below those which cause a reduction in strength. Using this type of material, the design methodology for composite structures could change from a design-for-hidden-damage approach (with the corresponding maintenance and inspection implications) to a design-for-visible-damage approach. This change in design methodology would be a significant advancement welcomed by the aircraft industry.

Future Plans

Additional tests, analyses, and structural efficiency studies will be conducted to further evaluate adhesive interleaving for improving damage tolerance and to evaluate the merit of the concept for aircraft structures applications.

ADHESIVE INTERLEAVING SIGNIFICANTLY IMPROVES COMPRESSION-AFTER-IMPACT STRENGTH



TECHNICAL HIGHLIGHT

EFFECT OF THICKNESS ON THE BUCKLING STRESS COEFFICIENT FOR ALUMINUM PLATES

Manuel Stein
Structural Mechanics Branch
Ext. 2813 March 1986
RTOP 505-63-31
Code RM WBS 56-2

Research Objective

Develop an accurate nonlinear two-dimensional theory for laminated and thick plates and shells which can predict the inplane stresses as well as transverse direct stress and transverse shearing stresses.

Approach

Nonlinear strain-displacement relations together with a series for the displacements using both the first few terms of a power series and trigonometric terms through-the-thickness are used to derive two-dimensional plate and shell equations by means of a three-dimensional variational theorem.

Accomplishment Description

For the present results stability relations are set up for transversely isotropic plates and these relations are solved for direct stress buckling of simply supported rectangular orthotropic plates and results are presented for isotropic (aluminum) plates in compression for which Young's modulus $E = 10.7 \times 10^6$ psi and Poisson's ration $\mu = 0.33$. These numerical results show the large effects of thickness on buckling stress and answer the question of how thin the plate must be in order to be able to use the results of classical thin plate theory. This analysis and others indicate that the equations derived here for plates and shells will capture the essence of the problem of determining all of the stresses including through-the-thickness stresses in laminated plates.

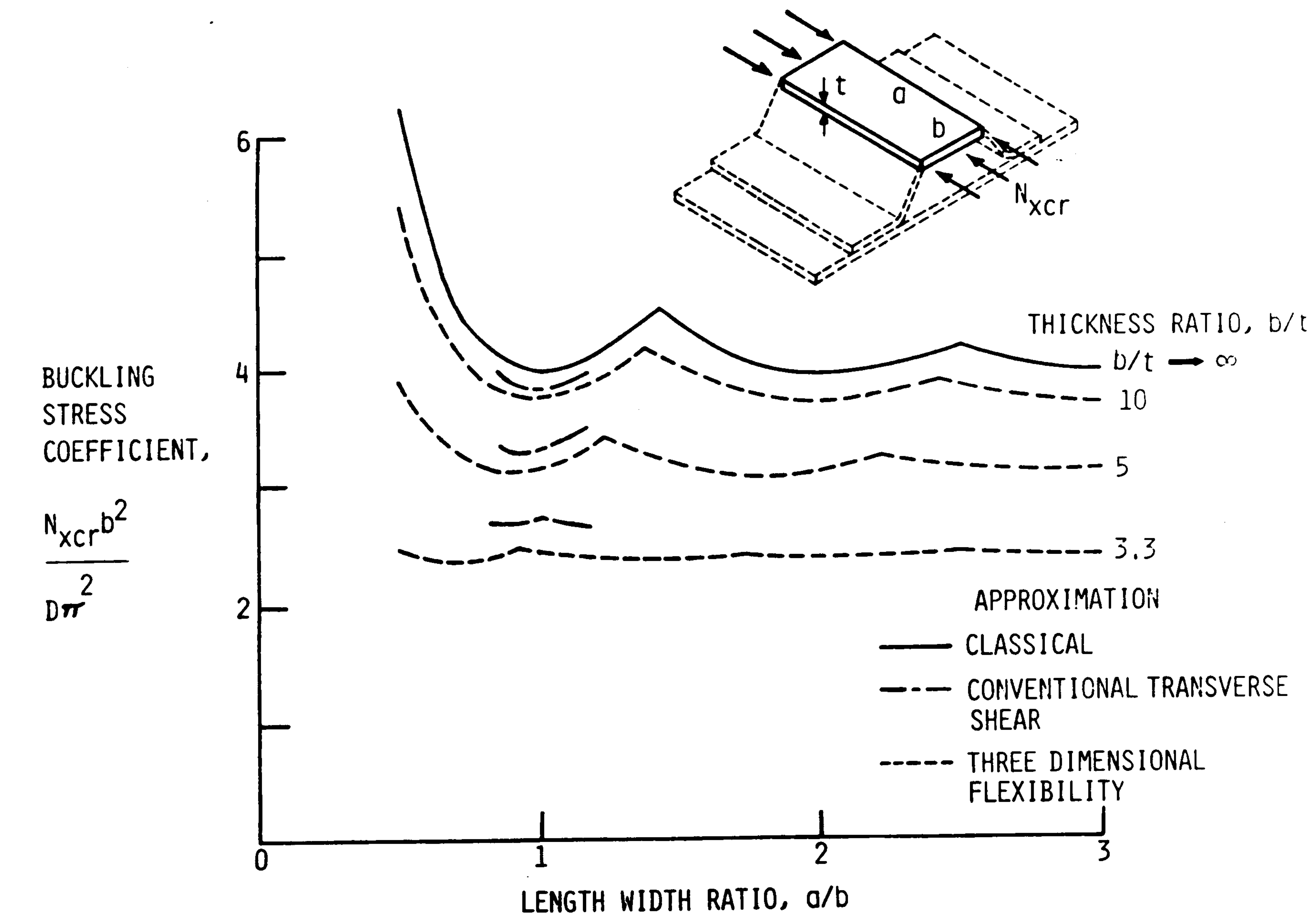
Significance

These results show that, for aluminum plates with thickness greater than 10 percent of the width of the plate, the effects of transverse shearing should be included in determining the compressive buckling stress. This lower buckling stress would be important in determining the buckling load of the crown of a hat stiffener in a stiffened panel in bending or compression and the start of postbuckling. Such hat-stiffened panels are widely used in both aeronautics and space construction.

Future Plans

A paper entitled, "Nonlinear Theory for Laminated and Thick Plates and Shells Including the Effects of Transverse Shearing," which includes these results, has been reviewed and will be published soon in the AIAA Journal. Buckling in compression and in shear of isotropic plates will be presented in the SSRC meeting in April 1986. Postbuckling results using this approach will be presented in May 1986 at the AIAA SDM meeting. Studies of flat and curved composite structures will be conducted in the future using the accurate theory.

EFFECT OF THICKNESS ON THE BUCKLING STRESS COEFFICIENT FOR ALUMINUM PLATES



NONLINEAR FAILURE ANALYSIS DEVELOPED FOR COMPRESSION-LOADED $[\pm\theta]_s$ LAMINATES

Mark J. Shuart
Structural Mechanics Branch, SDD
Ext. 2813 May 1986
RTOP 534-06-23
Code RM WBS 56-1

Research Objective
To develop a nonlinear failure analysis for multi-directional laminates loaded in compression.

Approach
Laminates with flat surfaces can have interior plies with initial geometric imperfections (waviness). A model has been developed for laminates with imperfections that idealizes each ply as a plate supported by an elastic foundation. The model applies to symmetric multi-directional laminates with linear material behavior. Nonlinear strain-displacement relations are used to study these laminates with initially imperfect plies.

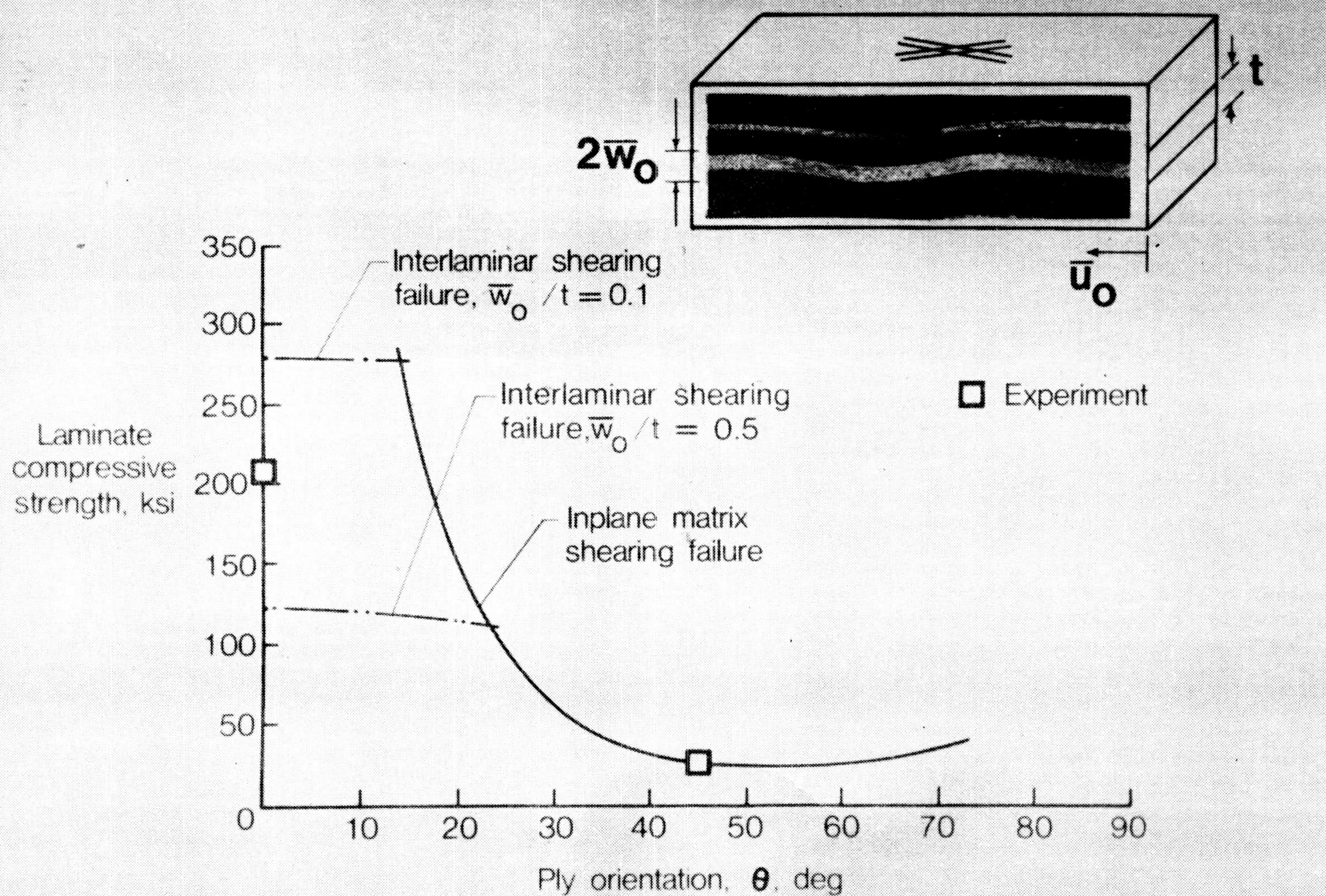
Accomplishment Description
Compression failure of a composite laminate is initiated by specific mechanisms. The present model is used to examine two shearing mechanisms that can initiate laminate failure: shearing between initially imperfect plies (interlaminar shearing) or shearing within a ply along the fiber-matrix interface (inplane matrix shearing). The laminate compressive strength is shown as a function of ply orientation for $[\pm\theta]_s$ laminates in the attached figure.

Laminate failure due to interlaminar shearing for laminates with imperfection-amplitude-to-ply-thickness ratios, $\bar{w}_o/t = 0.1$ and $\bar{w}_o/t = 0.5$, are plotted in the figure using a dashed line with one dot and a dashed with two dots, respectively. These imperfections bound those found in typical composite laminates. Laminate failure due to matrix shearing is plotted in the figure using a solid line. Experimental results for $[0]_{2s}$ and for $[\pm 45]_s$ laminates from the Advanced Composites Design Guide are represented as squares on the figure. The analytical results in the figure suggest that compressive failure of $[\pm\theta]_s$ laminates with $0° \leq \theta < 15°$ is due to interlaminar shearing when $\bar{w}_o/t \geq 0.1$. The $[0]_{2s}$ data are bounded by the analytical results for $\bar{w}_o/t = 0.1$ and $\bar{w}_o/t = 0.5$. Compressive failure of most $[\pm\theta]_s$ laminates $(15° \leq \theta \leq 75°)$ is due to inplane matrix shearing, and the $[\pm 45]_s$ data agree with the analysis. The failure of $[\pm\theta]_s$ laminates with $\theta > 75°$ appears to be initiated by compressive failure of the matrix, and this type of failure is not considered in the present model.

Significance
This analysis can predict compressive failure of composite laminates.

Future Plans
Document the laminate model and the results of the study, and perform additional tests to verify these results.

NONLINEAR FAILURE ANALYSIS DEVELOPED FOR COMPRESSION-LOADED $[\pm\theta]_s$ LAMINATES



LANGLEY SIFT TEAM QUANTIFIES SRM JOINT GAP OPENING AS A FUNCTION OF INITIAL CLEARANCES

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August 1986
RTOP 506-43-41
Code RM WBS 56-3

Research Objective

To understand the structural response of the SRM field joint by quantifying the gap opening between the tang and the inner clevis arm as a function of the initial assembly clearances.

Approach

Detailed three-dimensional-solid finite element models of a one-degree segment of the original and modified field joints were developed using the solid modeling software systems GEOMOD and SUPERTAB. Typical finite element models are shown on the left side of the figure. These models were analyzed using the EAL finite element code. A computational module to analyze the nonlinear contact problem of these joints was developed by the CSM Group and incorporated in EAL. Parametric studies were performed to quantify the gap opening as a function of initial clearances.

Accomplishment Description

An understanding of the physics of the SRM field joint was developed through parametric studies which identified structural response sensitivities. Joint modeling sensitivities include the contact regions, pin friction, initial clearances, pressure distribution, axial-load eccentricities, and plasticity. The relative rotation of the clevis and tang (rotations are opposite one another) is such that the inner clevis arm and the tang move apart causing a gap opening to develop at the O-ring. The modified tang uses a capture feature (shown in red on the left side of the figure) to limit the relative rotation that can occur between the inner clevis arm and the tang. Elastic, three-dimensional finite element analyses of the original and modified field joint concepts have quantified the SRM joint gap opening as a function of the initial clearances. Assuming an initial .010 in. clearance between the outer clevis arm and the tang, the gap opening was .032 in. for the original joint subjected to a 1000 psi pressure load and resulting axial load. Several analyses of the modified joint were performed with various values for the initial clearance between the capture feature and the inner clevis arm. These results, shown in the center of the figure, indicate that the gap opening can be significantly reduced with the capture feature compared to the results for the original joint--provided the initial clearances can be made small. For example, the gap opening of .032 in. for the original joint is reduced to .004 in. for the modified joint with a zero initial clearance (metal-to-metal contact) between the inner clevis arm and the capture feature. Calculations also indicate that if the initial clearance between the inner clevis arm and the capture feature exceeds .040 in., the modified joint provides no improvement over the original joint design.

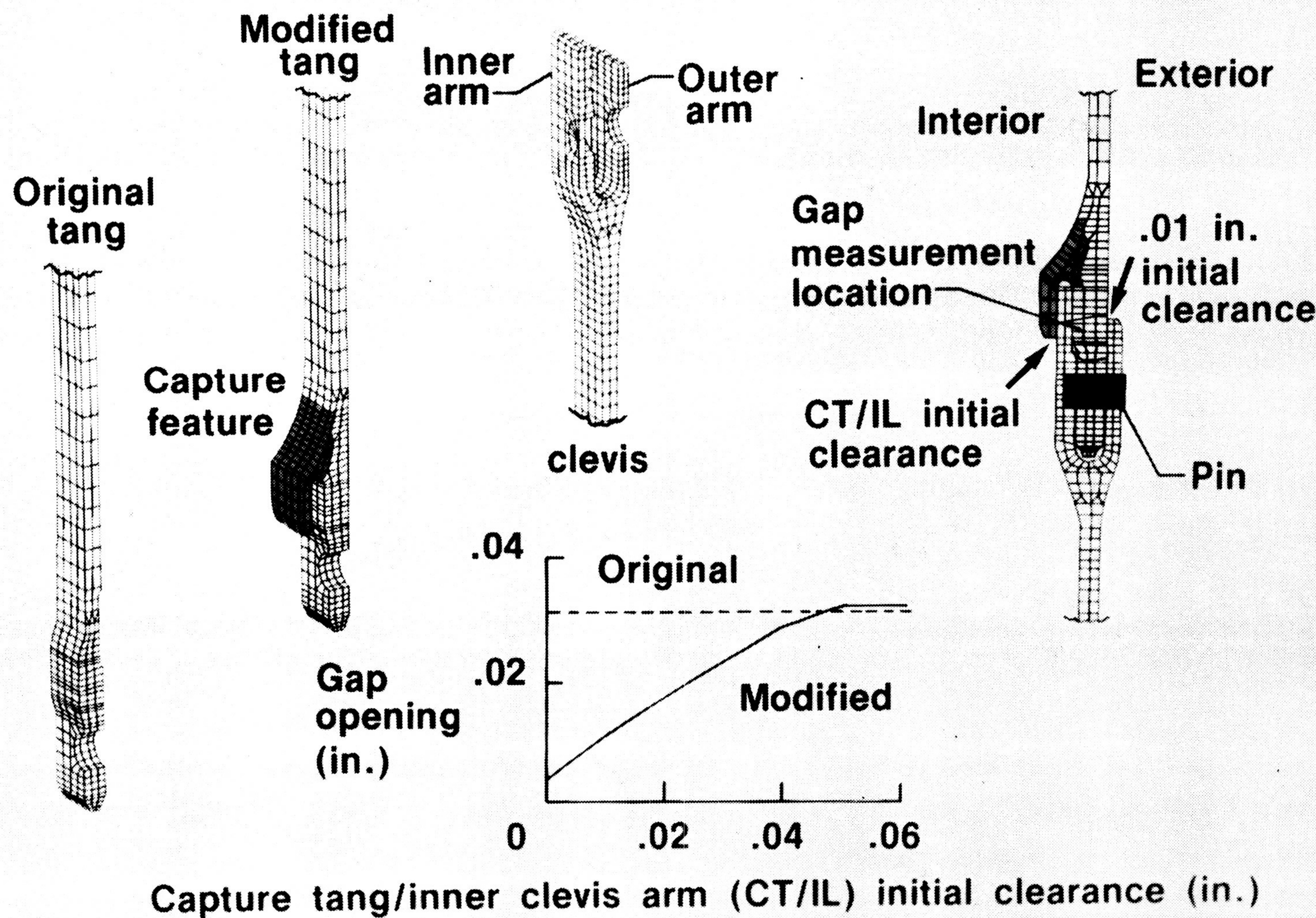
Significance

Inclusion of a capture feature on the SRM field joint will limit the relative rotation that can occur between the inner clevis arm and the tang. Therefore, the gap opening as measured midway between the O-rings on the inner clevis arm and the tang would be limited and thus prevent unseating of the O-rings if the initial clearance is less than .040 in. Issues related to assembly, plasticity and SRM case reuse have not been addressed in this study.

Future Plans

The analytical models developed to date will be used to investigate the interference fit concept of the Marshall Space Flight Center SRM Redesign Team and to assess the structural integrity of the proposed SRM joint design fix.

LANGLEY SIFT TEAM QUANTIFIES SRB JOINT GAP OPENING AS FUNCTION OF INITIAL CLEARANCES



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VIII PUBLICATIONS AND PRESENTATIONS

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VIII PUBLICATIONS AND PRESENTATIONS

The FY 1986 accomplishments resulted in a number of publications and presentations. They are listed below as Formal Reports; Quick-Release Technical Memorandums; Contractor Reports; Journal Articles and Other Publications; Meeting Presentations; Technical Talks; Computer Programs; Tech Briefs; and Patents.

Formal Reports

1. Daugherty, R. H.; and Stubbs, S. M.: A Study of the Cornering Forces Generated by Aircraft Tires on a Tilted, Free-Swiveling Nose Gear. NASA TP-2481, October 1985

2. Dorsey, J. T.: Dynamic Characteristics of Power-Tower Space Stations With 15-Foot Truss Bays. NASA TM-87684, July 1986

3. Fasanella, E. L.; Alfaro-Bou, E.; and Hayduk, R. J.: Impact Data From a Transport Aircraft During a Controlled Impact Demonstration. NASA TP-2589, September 1986

4. Fichter, W. B.: A Simple Nonlinear Joint Model. NASA TM-87749, August 1986

5. Hayduk, R. J. (Compiler): Full-Scale Transport Controlled Impact Demonstration. NASA CP-2395, January 1986

6. Jackson, K. E.: Abrasion Behavior of Aluminum and Composite Skin Coupons, Stiffened Skins, and Stiffened Panels Representative of Transport Airplane Structures. NASA TP-2520, AVSCOM TR 85-B-7, November 1985

7. Nemeth, M. P.; Stein, M.; and Johnson, E. R.: An Approximate Buckling Analysis for Rectangular Orthotropic Plates With Centrally Located Cutouts. NASA TP-2528, February 1986

8. Stubbs, S. M.; and Tanner, J. A.: Technique for Measuring Side Forces on a Banked Aircraft With a Free-Swiveling Nose Gear. NASA TM-87719, August 1986

9. Thurston, G. A.; and Bains, N. J. C.: Solution of the Symmetric Eigenproblem $AX = \lambda BX$ by Delayed Division. NASA TP-2514, March 1986

Quick-Release Technical Memorandums

10. Bales, K. S.: Structures and Dynamics Division Research and Technology Plans for FY 1986 and Accomplishments for FY 1985. NASA TM-87742, July 1986

11. Belvin, W. K.; and Edighoffer, H. H.: Experimental and Analytical Generic Space Station Dynamic Models. NASA TM-87696, March 1986

12. Card, M. F.; Heard, W. L., Jr.; and Akin, D. L.: Construction and Control of Large Space Structures. NASA TM-87689, February 1986

13. Dorsey, J. T.: Structural Performance of Space Station Trusses With Missing Members. NASA TM-87715, May 1986

14. Dorsey, J. T.; Sutter, T. R.; Lake, M. S.; and Cooper, P. A.: Dynamic Characteristics of Two 300 KW Class Dual Keel Space Station Concepts. NASA TM-87680, February 1986

15. Fasanella, E. L.; and Alfaro-Bou, E.: Vertical Drop Test of a Transport Fuselage Section Located Aft of the Wing. NASA TM-89025, September 1986

16. Greene, W. H.; Knight, N. F., Jr.; and Stockwell, A. E.: Structural Behavior of the Space Shuttle SRM Tang-Clevis Joint. NASA TM-89018, September 1986

17. Housner, J. M.; McGowan, P. E.; Abrahamson, A. L.; and Powell, M. G.: The LATDYN User's Manual. NASA TM-87635, January 1986

18. Jegley, D. C.: Effects of Thickness and Ply Orientation on Buckling of Laminated Plates. NASA TM-87691, February 1986

19. Juang, J-N.: Mathematical Correlation of Modal Parameter Identification Methods Via System Realization Theory. NASA TM-87720, April 1986

20. Lake, M. S.; and Bush, H. G.: An Analytical Investigation of a Conceptual Design for the Space Station Transverse Boom Rotary Joint Structure. NASA TM-87665, January 1986

21. Lotts, C. G.; and Greene, W. H.: Experiences With a Preliminary NICE/SPAR Structural Analysis System. NASA TM-87586, October 1985

22. Shuart, M. J.: Short-Wavelength Buckling and Shear Failures for Compression-Loaded Composite Laminates. NASA TM-87640, November 1985

23. Sohi, M. M.; Hahn, H. T.; and Williams, J. G.: The Effect of Resin Roughness and Modulus on Compressive Failure Modes of Quasi-Isotropic Graphite/Epoxy Laminates. NASA TM-87604, March 1986

24. Wu, K. C.; and Lake, M. S.: Analysis of a Single-Fold Deployable Truss Beam Preloaded by Extension of Selected Face Diagonal Members. NASA TM-87673, April 1986

Contractor Reports

25. Adams, L. R.; and Hedgepeth, J. M.: Batten Augmented Triangular Beam. NASA CR-172461, February 1986 (NAS1-17536, Astro Research Corp.)

26. Derian, E. J.; and Hyer, M. W.: Large Deformation Dynamic Bending of Composite Beams. NASA CR-4006, August 1986 (NAG1-343, Virginia Polytechnic Institute and State University)

27. Duke, J. C., Jr.; Post, D.; Czarnek, R.; and Asundi, A.: Measurement of Displacement Around Holes in Composite Plates Subjected to Quasi-Static Compression. NASA CR-3989, June 1986 (NAG1-193, Virginia Polytechnic Institute and State University)

28. Hahn, H. T.; Sohi, M.; and Moon, S.: Compression Failure Mechanisms of Composite Structures. NASA CR-3988, June 1986 (NAG1-295, Washington University)

29. Reddy, J. N.: A Refined Shear Deformation Theory for the Analysis of Laminated Plates. NASA CR-3955, January 1986 (NAG1-459, Virginia Polytechnic Institute and State University)

30. Stehlin, P.; and Brogan, F. A.: Computational Reduced Basis Techniques in Nonlinear Structural Analysis. NASA CR-178096, September 1986 (NAS1-16723, Lockheed Missiles & Space Company, Inc.)

Journal Articles and Other Publications

31. Anderson, M. S.; and Nimmo, N. A.: Dynamic Characteristics of Statically Determinate Space-Truss Platforms. Journal of Spacecraft and Rockets, Volume 23, No. 3, May-June 1986, p. 303-307

32. Anderson, M. S.; and Williams, F. W.: Natural Vibration and Buckling of General Periodic Lattice Structures. AIAA Journal, Volume 24, No. 1, January 1986, p. 163-169

33. Greene, W. H.: Minimum Weight Sizing of Guyed Antenna Towers. Journal of Structural Engineering, Volume 111, No. 10, October 1985, p. 2121-2137

34. Horne, W. B.; Yager, T. J.; and Ivey, D. L.: Recent Studies to Investigate Effects of Tire Footprint Aspect Ratio on Dynamic Hydroplaning Speed. The Tire Pavement Interface, ASTM STP 929, 1986, p. 26-46

35. Horta, L. G.; and Juang, J-N.: Identifying Approximate Linear Models for Simple Nonlinear Systems. Journal of Guidance, Control, and Dynamics, Volume 9, No. 4, July-August 1986, p. 385-390

36. Housner, J. M.; and Belvin, W. K.: Dynamic Response and Collapse of Slender Guyed Booms for Space Application. Journal of Spacecraft and Rockets, Volume 23, No. 1, January-February 1986, p. 88-95

37. Howell, W. E.; Perez, S. E.; and Vogler, W. A.: Aircraft Tire Footprint Forces. The Tire Pavement Interface, ASTM STP 929, 1986, p. 110-124

38. Juang, J-N.; Horta, L. G.; and Robertshaw, H. H.: A Slewing Control Experiment for Flexible Structures. Journal of Guidance, Control, and Dynamics, Volume 9, No. 5, September-October 1986, p. 599-607

39. Juang, J-N.; and Pappa, R. S.: Effects of Noise Modal Parameters Identified by the Eigensystem Realization Algorithm. Journal of Guidance, Control, and Dynamics, Volume 9, No. 3, May-June 1986, p. 294-303

40. Juang, J-N.; Turner, J. D.; and Chun, H. M.: Closed-Form Solutions for Feedback Control With Terminal Constraints. Aeronautics/Space Technology in the Soviet Union, Volume 3, No. 12, December 1985, p. 86-92

41. Juang, J-N.; Turner, J. D.; and Chun, H. M.: Closed-Form Solutions for a Class of Optimal Quadratic Regulator Problems With Terminal Constraints. Journal of Dynamic Systems, Measurements and Control, Volume 108, No. 1, March 1986, p. 44-48

42. Knight, N. F., Jr.: Nonlinear Structural Dynamic Analysis Using a Modified Modal Method. AIAA Journal, Volume 23, No. 10, October 1985, p. 1594-1601

43. Knight, N. F., Jr.; and Starnes, J. H., Jr.: Postbuckling Behavior of Axially Compressed Graphite-Epoxy Cylindrical Panels With Circular Holes. Journal of Pressure Vessel Technology, Volume 107, November 1985, p. 394-402

44. Sawyer, J. W.: Effect of Stitching on the Strength of Bonded Composite Single Lap Joints. AIAA Journal, Volume 23, No. 11, November 1985, p. 1744-1748

45. Shuart, M. J.; and Williams, J. G.: Compression Behavior of ±45-Degree-Dominated Laminates With a Circular Hole or Impact Damage. AIAA Journal, Volume 24, No. 1, January 1986, p. 115-122

46. Stein, M.: Nonlinear Theory for Plates and Shells Including the Effects of Transverse Shearing. AIAA Journal, Volume 24, No. 9, September 1986, p. 1537-1544

47. Sun, C. T.; and Juang, J-N.: Modeling Global Structural Damping in Trusses Using Simple Continuum Models. AIAA Journal, Volume 24, No. 1, January 1986, p. 144-150

48. Thurston, G. A.; Brogan, F. A.; and Stehlin, P.: Postbuckling Analysis Using a General-Purpose Code. AIAA Journal, Volume 24, No. 6, June 1986, p. 1013-1020

49. Turner, J. D.; Chun, H. M.; and Juang, J-N.: Closed-Form Solutions for a Class of Optimal Quadratic Tracking Problem. Journal of Optimization Theory and Application, Volume 47, No. 4, December 1985, p. 465-481

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Meeting Presentations

50. Anderson, M. S.; and Williams, F. W.: BUNVIS-RG: An Exact Buckling and Vibration Program for Lattice Structures, With Repetitive Geometry and Substructuring Options. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and Materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0863-CP

51. Belvin, W. K.; and Edighoffer, H. H.: Dynamic Analysis and Experiment Methods for a Generic Space Station Model. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and Materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0838-CP

52. Boitnott, R. L.; and Carden, H. D.: Drop Testing and Analysis of Six-Foot-Diameter Graphite-Epoxy Frames. Presented at the American Helicopter Society national Specialists' Meeting on Crashworthy Design of Rotorcraft, April 7-9, 1986, Atlanta, Georgia. In Proceedings

53. Bostic, S. W.; and Fulton, R. E.: Implementation of the Lanczos Method for Structural Vibration Analysis on a Parallel Computer. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0930-CP

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55. Carden, H. D.; Boitnott, R. L.; and Jackson, K. E.: Composite Crash Dynamics. Presented at the AFSC/WPAFB Eleventh Annual Mechanics of Composites Review, October 22-24, 1985, Dayton, Ohio. Abstract in Proceedings, p. 26

56. Cooper, P. A.; Sutter, T. R.; Lake, M. S.; and Young, J. W.: Multidisciplinary Capability for Analysis of the Dynamics and Control of Flexible Space Structures. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and Materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0961-CP

57. Daugherty, R. H.; and Stubbs, S. M.: The Generation of Tire Cornering Forces in Aircraft With a Free-Swiveling Nose Gear. Presented at the SAE Aerospace Technology Conference & Exposition, October 14-17, 1985, Long Beach, California. SAE Paper No. 851939

58. Davis, P. A.; Stubbs, S. M.; and Tanner, J. A.: Aircraft Landing Dynamics Facility, A Unique Facility With New Capabilities. Presented at the SAE Aerospace Technology Conference & Exposition, October 14-17, 1985, Long Beach, California. SAE Paper No. 851938

59. Fasanella, E. L.; Widmayer, E.; and Robinson, M. P.: Structural Analysis of the Controlled Impact Demonstration of a Jet Transport Airplane. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and Materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0939-CP

60. Hanks, B. R.; Allen, J. L., Jr.; and Fontana, A.: Status of the Mast Experiment. Presented at the NASA Marshall Workshop on Structural Dynamics and Control of Large Flexible Structures, April 22-24, 1986, Huntsville, Alabama. Proceedings pending

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62. Heard, W. L., Jr.: ACCESS (Assembly Concept for Construction of Erectable Space Structure) - A Shuttle Flight Experiment. Presented at the IEEE 18th Annual Electronics and Aerospace Systems Conference (EASCON 85), October 28-30, 1985, Washington, DC. In proceedings, p. 157-165

63. Heard, W. L., Jr.; and Watson, J. J.: Results of the ACCESS Space Construction Shuttle Flight Experiment. Presented at the AIAA 3rd Space Systems Technology Conference, June 9-12, 1986, San Diego, California. AIAA Paper No. 86-1186-CP

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65. Horner, G. C.: Active Damping Experiments. Presented at the NASA Marshall Workshop on Structural Dynamics and Control of Large Flexible Structures, April 22-24, 1986, Huntsville, Alabama. Proceedings pending

66. Housner, J. M.; and McGowan, P. E.: An Analytical Treatment of Discretely Varying Constraints and Inertial Properties in Multi-body Dynamics. Presented at the AIAA/ASME, et al., 27th Structures, Structural Dynamics and Materials Conference, May 19-21, 1986, San Antonio, Texas. AIAA Paper No. 86-0869-CP

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16. Abstract

This paper presents the Objectives, FY 1987 Plans, Approach, and FY 1987 Milestones for the Structures and Dynamics Division's research programs. FY 1986 Accomplishments are presented where applicable. This information is useful in program coordination with other governmental organizations in areas of mutual interest.

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